ROBERT HALLER HUTCHINSON.

It is with the deepest regret that we have to record the loss of Mr. Hutchinson, who died at his home in Acton on Tuesday, March 19th, 1935, aged 51.

To his widow and other relatives the President of the Institution, Sir Walter Kent, has conveyed the deep sympathy and regret of all those Members who knew and admired him, and who value the great work he did for the Institution. His death leaves a gap that will be indeed hard to fill.

Born at Richmond, Surrey, in 1884, he was educated at Eastown and Berkhampstead, receiving his technical education at Kings College and the Central Technical College, South Kensington. His apprenticeship was served with the British Westinghouse Co., Manchester, with whom he spent eight years after its completion. His subsequent appointments were with Vickers, Ltd., the Austin Motor Company, D. Napier and Son, Ltd., Armstrong Siddeley Motors, and the De Havilland Aircraft Company.

Joining the Institution in 1922, within a year of its foundation, he became a Member of Council in February, 1924, and President of the Institution for the two years 1925-1927. From that date until his death this month, he was Chairman of the Finance and Development Committee, presiding at nearly all its meetings till his last illness. He was also Chairman of the Institution's Advisory Committee to the City and Guilds of London Institute, and took a leading part in every major activity of the Institution for many years.

A man of strong personality and decided views, he was unsparing in his efforts to help in building the Institution on sound foundations, never wavering in his belief that one day it would rank with the greatest among the engineering institutions of the country.

MATERIAL INSPECTION.

Paper presented to the Institution, Western Section, by E. R. Gadd, M.Inst.Met.

ADVANCES in the technique of material inspection have been extremely rapid during the last ten to fifteen years. This has been due very largely to two main causes: (1) The desire for the maintenance of uniformity in the case of mass-produced articles; (2) the desire for better quality and still better quality in those cases where, by reason of design limitations, the article or component may have to withstand stresses of abnormal severity.

An illustration of the first factor may be found in a study of the production methods used for motor car construction. If the motor car manufacturer desires to produce very large quantities of a specified model, this is only possible where the raw materials at his disposal are consistent in their physical and mechanical properties. The materials may not have to be superlatively good, but successive consignments must show the same properties in order that the production processes (machining, forging, pressing, casting, etc.) may always be carried out under identical conditions. Immediately the process has to be altered to suit a batch of material, the mass production system breaks down.

Referring now to factor (2), the outstanding examples under this heading are aircraft and aircraft engine manufacture. High performance in aircraft can only be accomplished by a combination of weight reduction and increased aerodynamic efficiency. It is quite obvious that much can be done in the way of correct aerodynamic design, but the weight question will always be to the fore in any aircraft development.

Saving of weight on aircraft and aircraft engines is partly a question of design and partly a question of the material available. Since, however, the most perfect design is limited by the materials at the designer's disposal, the question of the material quality becomes of paramount importance.

This talk will refer largely to the inspection of materials used in the manufacture of aircraft and aircraft engines. The main reason is, of course, that the author's experience has been confined mostly to aero engine work, but apart from that consideration I believe that the methods of inspection given to aircraft materials will, in due course, be widely used for other engineering purposes.

Bristol, January 11th, 1935

It might be mentioned at this stage that many of the inspection methods that will be described have been developed at The Bristol Aeroplane Co., with whom the author is associated, these inspection methods being additional to those normally required by the Aeronautical Inspection Directorate.

In order to understand the different types of defects found in materials, it is necessary to consider in some detail, the manufacturing processes to which they are subjected. Space does not permit of a description of the recovery of metals from their ores or to go into great detail regarding methods of melting and alloying, although it must be admitted that these processes have an important influence on the quality of the final product. It is proposed, however, to deal at some length with the ingot casting process, it being the author's conviction that it is at this stage in the manufacturing process that the greatest attention and care should be exercised. However excellent the technique of the forger, stamper, wire drawer, etc., if the raw material is inferior, a satisfactory product cannot be achieved.

In considering the casting of ingots it is not possible to cover all the commercial materials used for engineering purposes. It is proposed, in fact, to select one steel, and an effort will be made to show how the defects of steel casting have their counterpart in other alloys such as aluminium, bronze, etc.

Steel melting is carried out in various types of furnaces, involving different methods of heating and processes of refining. The more commonly known and used are the open hearth, electric arc, high frequency electric and crucible furnaces. The open hearth is still used for the largest quantities of steel, and although great strides have been made in the technique of this class of melting, the quality of the final product is still somewhat inferior to that obtained from the other types mentioned.

The electric arc method has come into great prominence in recent years. Compared with the open hearth method it has the advantage that the metal is under much better control, and there is less tendency for the metal to pick up impurities from the furnace atmosphere. It is interesting to note that stainless steels are now made exclusively by the electric furnace method. The crucible process is useful for making small quantities of high grade steel, especially the higher carbon and tool steels.

The high frequency electric furnace method is also now being rapidly adopted for small quantities of special steels, such as tool steels and stainless steels. Both the crucible and high frequency electric methods are restricted to small quantity production, and only small ingots are capable of being cast by these methods.

Casting the Ingot.

Steel is cast in ingot moulds of cast iron, the latter varying considerably in size according to the purpose for which the metal is required. Ingots may vary in size from half-a-hundredweight up to 200 tons. When the molten metal is poured into the mould the chilling effect of the latter tends to freeze the metal immediately in contact with it. As a result of this the metal at the ingot walls freezes momentarily, oxidises, and then becomes almost immediately enveloped by the rising metal. This trapping of oxidised metal at the walls is also accompanied by a tendency to entrap gases released from the metal. These surface inclusions are common defects in all ingots.

When the mould is filled the freezing of the steel begins to take place first at the outside surfaces. Steel crystals grow inward from the walls and bottom, growth in any other direction being restricted by adjacent crystals. This type of crystal formation is known as columnar. The columnar crystals growing from the bottom of the mould meet those from the sides forming a marked line of weakness along their junctions. When the metal in the centre of the mould has become sufficiently low in temperature, crystals begin to form from many nuclei at the same time, growth taking place in all directions. These crystals are called free crystals.

While these interesting things have been happening, another important factor comes into evidence. As the molten metal cools considerable shrinkage takes place. The metal at the walls and bottom has become solid, so that maximum contraction takes place in the centre. This central shrinkage may become so marked as to form what is known as " pipe." This particular defect presents one of the most serious problems in ingot casting, because it may occur in certain forms which are not detectable by any inspection method. One special variety known as intermittent pipe may persist through a large proportion of the ingot. Pipe is also usually accompanied by segregation of non-metallic impurities such as manganese, sulphide, iron silicate, and iron phosphides. These segregates, together with gas holes, may also occur at the junction of the columnar and free crystals. Silicate segregates are often found at the lower end of the ingot, and when they occur here are confined to a roughly cone-shaped area.

The defects of melting and ingot casting may be summarised as follows :

(1) Wrong composition.

(2) Impurities too high.

(3) Trapping of oxidised metal at surface of the ingot often accompanied by subcutaneous gas holes.

(4) Excessive columnar crystals forming planes of mechanical weakness.

(5) Particular type of columnar crystal weakness at the junction of the sides and bottom of ingot.

(6) Central pipe, especially the variety known as intermittent or "secondary pipe."

(7) Central segregation of sulphides, phosphides, etc. Similar segregations at the junction of columnar and free crystals.

(8) Internal blowholes due to trapped gases.

(9) Segregation of silicates at the lower end of the ingot.

(10) Internal cracks (sometimes known as hair cracks) due to solid shrinkage of the ingot.

How are these defects controlled and inspected?

(1) Composition depends on correct mixing and furnace control. It is checked by rapid chemical analysis made on a small sample taken from the melt. Corrections may be made and the casting proceeded with.

(2) Total impurities are controlled by adequate slagging and refining methods.

(3) Trapped oxidised metal and subcutaneous blowholes are removed from the surface of the ingot subsequent to casting by chipping and machining methods.

(4) Columnar crystal formation is regulated by the temperature of the metal and rate of cooling in the ingot mould. It is observed by surface examination after cropping and etching (see also remarks on "pipe").

(5) Columnar crystal weakness at bottom of the ingot is removed by cutting off five per cent. of the ingot at this end.

(6) Pipe is controlled by the provision of a "dozzle" at the top of the ingot. This is a device for feeding in molten metal as the metal in the centre contracts. Any pipe which may exist in spite of this is removed by cutting off 25 per cent. of the ingot from the top end. Intermittent pipe is difficult to check, but should not occur under modern steel works conditions. Indication of its existence may be given by the presence of segregations referred to under (7).

(7) Segregations of non-metallics (sulphides, etc.) are controlled by attention to ingot temperatures and cooling conditions. It is observed by examination of the top surface of the ingot after cropping. Etching and sulphur print methods are used for this purpose.

(8) Internal blowholes, though undesirable, are not always easily avoidable. If the surfaces of the holes are clean they will often weld up during subsequent forging and give no further trouble. An excessive number of such blowholes should, however, entail rejection of the ingot. They may be observed by the etching method referred to above.

(9) The segregation of silicates at the lower end of the ingot is removed by the five per cent. discard.

(10) Internal cracks are prevented by slow cooling of the ingot after casting. These cracks are mostly found in alloy steels which are susceptible to air hardening. They are discovered by the etching process after cropping.

In regard to the reference to sulphide and silicate segregations a further explanatory word might be added. All steels contain inclusions of manganese sulphide and iron silicate. Modern methods of steel making have tended to reduce the number and size of these undesirable inclusions considerably, and provided they are evenly distributed they are not so serious. If, however, they are confined to a particular area they may reduce the resistance of the material to fatigue very considerably.

It is hoped that the author will be forgiven for going into such detail in this description of the casting of the ingot. So many of the defects found on finished components are directly traceable to the ingot, however, that knowledge of the origin of these defects becomes an important asset in building up an efficient material inspection procedure. What has been so far described has been related entirely to the manufacture of steel, but the general principles underlying the satisfactory casting of steel ingots may be broadly applied to the casting of ingots of aluminium alloys, bronzes, brasses, nickel base alloys, and so on. The types of impurities differ, of course, but many of the major defects such as pipe, columnar crystals, internal cracks, and blowholes are common to all. The casting of the ingot is probably the most important stage in the manufacture of any material.

Wrought Material.

It is now desired to refer to defects in wrought material. Ingots of metal may be drawn or rolled into bars, rolled into sheets, hammered into forgings, stampings, and so on. Defects of many kinds are produced during these processes. If the original ingot has been faulty we may expect :

(1) Seams and roaks in bars. These defects are directly traceable to surface defects on the ingot which have not been adequately removed by the chipping and machining operations.

(2) Breakdown of the material due to one or more of the following causes : (*a*) Traces of ingot pipe persisting in the billet ; (*b*) central segregation of non-metallic impurities ; (*c*) coarse structure due to presence of columnar (sometimes known as dendritic) crystals ; (*d*) presence of internal blowholes.

Defects due entirely to the working operations may be summarised as follows :

(1) Breakdown of the material due to the following causes :

(*a*) Temperature of working too high or too low ; (*b*) the rate of deformation too rapid or too slow ; (*c*) incorrect tool design.

(2) Permanent structural damage to the material if it is exposed to too high temperatures for long periods.

(3) Laps (a defect common to bar material) caused by the rolling in of the flash left from the previous pass in the rolls. A defect similar to laps in bars may occur in forgings and stampings where the part is formed in a series of dies.

Heat Treatment.

After the various working operations have been carried out, suitable heat treatments are applied to the material which, subject to certain tests, is then ready for dispatch to the user.

The heat treatments applied to materials vary in many ways. They may be grouped under the following main headings :

(1) Hardening and tempering.
(2) Case-hardening.
(3) Normalising.
(4) Annealing.

Hardening and Tempering.

Many materials may have their mechanical properties improved considerably by heating to a suitable temperature, followed by rapid cooling in some medium such as oil or water. In some cases even air cooling is sufficient (as in the case of air hardening steels). Many steels, certain bronzes, aluminium alloys, and magnesium alloys are susceptible to hardening by heat treatment. The hardening operation raises the breaking strength of a material, but there is usually a corresponding reduction in the ductility and toughness. In order to obtain a proper balance of strength and ductility, it is necessary to follow the hardening by a tempering operation. This consists of re-heating the material to a predetermined temperature below the hardening temperature, causing a partial breakdown of the hardened structure. A large variety of combinations of strength and ductility may be obtained by a correct use of the hardening and tempering operations.

Case-Hardening.

This operation is used where it is desired to combine in one material good ductility plus very high surface hardness. It is mainly confined to steels, although many attempts have been made and are being made to treat aluminium and magnesium alloys by some such surface treatment. The case-hardening of steels is effected in three operations, carburising, refining, and hardening.

In the carburising operation the parts are packed in boxes together with carburising powder. The latter consists of wood or animal

charcoal plus chemical salts which act as accelerators. In aircraft work it is usual to use a carburising compound consisting of approximately 60 per cent. wood charcoal and 40 per cent. of sodium or barium carbonate. After packing, the carburising boxes are heated to a predetermined temperature (which may vary between 880-920° C., according to the type of steel) and maintained at this temperature for several hours. The result of this treatment is that carbon is introduced into the surface of the steel, the depth of penetration being dependent on the temperature and time of soaking. After carburising, the structure of the core of the material is found to be coarsened, and thereby weakened, and in order to restore it to its normal condition, the part undergoes an operation known as refining. This consists in heating the component to a temperature at which re-crystallisation takes place and then cooling in air, oil, or water. The temperature used for the refining operation is usually too high to obtain the maximum hardness properties of the case, so that a third heat treatment operation is necessary to effect this. This is known as hardening. After heating to the hardening temperature, the parts are again quenched in oil or water.

Normalising.

Some materials (particularly low or medium carbon steels not requiring case-hardening) are used in their normalised condition. This usually involves the heating of the material to the temperature normally required for hardening, followed by cooling in air. The normalising treatment restores material which has been overheated in working (forging, rolling, etc.) to a condition similar to that described in the refining operation after carburising. It is also valuable in removing forging and machining stresses.

Annealing.

The annealing treatment is used for softening materials. It involves the heating of a part to a predetermined temperature, followed by cooling in air or water. The temperature selected is such that, after cooling the component, it is in its softest condition. Like the normalising treatment, internal strains left by working or machining are removed, but normalising differs in that a material is not necessarily softened by its action. Materials supplied to the user in the softened condition include case-hardened steels (since the case-hardening operation is usually carried out after part machining). Aluminium alloys and magnesium alloy castings are very often supplied and used in their annealed condition.

There are many types of defects possible during heat treatment. It is not proposed to deal with them at this stage, but reference will be made to them under later sections dealing with raw material inspection, and defects in part-machined and finished components.

While not coming strictly under the heading of heat treatment, it is an opportune moment to refer to another condition in which material may be supplied to the user. This is known as the " cold worked " condition. The term " cold working " is somewhat misleading because this operation is not always carried out at room temperature. It does imply, however, that the material is worked at a temperature sufficiently below the annealing temperature for it to harden by deformation.

Mechanical Testing.

It is necessary at this stage to refer in some detail to mechanical testing. All materials used in aircraft construction, and indeed in most other engineering construction work, have been suitably graded and grouped to cover various requirements of mechanical strength. There are, of course, other physical properties which may be required of a material, such as resistance to heat, resistance to certain types of corrosion, resistance to wear, high expansion under heat, high heat conductivity, etc. For the moment we will consider mechanical properties only. Under this heading must be mentioned tensile properties, resistance to impact, and hardness. How are these tests carried out and what do we learn from them ?

Tensile Test.

This consists in loading a test piece of suitable dimensions in tension until rupture occurs. A number of useful properties are determined during the tensile tests, namely :

(*a*) *Breaking strength or ultimate tensile strength.*—This figure is obtained by dividing the load (in tons) required to produce rupture by the original cross sectional area (in square inches) of the test piece. The breaking strength is thus referred to in tons per square inch.

(*b*) *Elastic limit.*—When a test piece is stressed in tension the elongation produced by increasing load increments may be measured by an instrument known as an extensometer. This is merely a device which can be clamped to the test piece and registers the extensions magnified by a system of levers or by optical methods. If a curve is plotted showing the relation between load and extension, it will be noted that the first part of the curve is a straight line. This means that for low loads the extensions are directly proportional to the load. The point at which the curve departs from a straight line is called the " limit of proportionality " or " elastic limit." Stresses below the " elastic limit " produce only temporary extensions, since immediately after removing the load the test piece returns to its original dimensions. Stresses beyond the " elastic limit " produce permanent extensions.

(*c*) *Yield Point.*—This property may be found by plotting a load-

extension curve sufficiently far, but for normal test purposes it is observed in a much simpler manner. The test piece is marked with centre pops at two points on its parallel portion a fixed distance apart. These " gauge points " as they are called are used finally for determining the elongation (to be described later). When observing the yield point a pair of dividers is used to check the increase in length between the gauge points. When a sudden and marked increase occurs the yield point has been reached. The yield point may also be observed by a sudden drop in the beam of the testing machine.

(*d*) *Proof Strength.*—This test has been introduced in recent years, partly as a substitute for the yield point, but in a more general way to cover certain classes of materials in which no well-defined yield point occurs. Aluminium alloys, magnesium alloys, and certain classes of steels come in this category. The object of the " Proof Test " is to determine the stress which produces a certain percentage of permanent extension. For most aircraft specifications where proof stress test is specified, the permanent extension figure is fixed at 0.1 per cent. of the " gauge length." The proof test requires the use of an extensometer, the test piece being loaded until the 0.1 per cent. extension is produced. The load is noted, the calculated stress being compared with the minimum figure required by the specification. In some cases 0.2 and 0.5 per cent. proof figures may be required for special purposes.

(*e*) *Elongation and Reduction of Area.*—These properties are a measure of the ductility of the material. Both properties are very easily determined from the tensile test. In measuring elongation it is necessary to mark off on the parallel portion of the test piece a fixed distance by two centre pops. This distance is known as the " gauge length " (already referred to above). After the test piece has been broken, the two halves are placed together again, and the distance between the pop marks again measured. An increase in length is found, which is calculated as a percentage increase over the original " gauge length." This is known as " elongation per cent." When a test piece elongates, there is naturally some reduction in the diameter. In many materials this reduction is fairly uniform over the whole of the parallel portion of the test piece. In other cases (and this applies specially to steels) the reduction is confined to the portion of the test piece where fracture occurs. In the latter cases this is a simple matter to measure the reduced diameter, and from this obtain the " reduction of area," expressing it as a percentage of the original area. While elongation percentage appears in specifications for all materials, the reduction of area is nowadays practically confined to steel specifications.

(*f*) *Modulus of Elasticity.*—While this property is not usually determined during normal routine testing, it is important to know

how it can be calculated when required. Referring to the load extension curves described under "elastic limit" it was shown that up to the elastic limit the extensions were proportional to the load. In other words the load : extension ratio is consistent within the elastic range. If now the load : extension ratios are examined on a number of materials such as steels, aluminium alloys and magnesium alloys, a striking fact emerges. For a given load, steels deflect least, aluminium alloys much more, and magnesium alloys much more again. In other words steel has the greatest stiffness, the other alloys mentioned being inferious in certain definite proportions. The question of the relative stiffness of alloys is very important to the designer, and in calculating the effect of stress on a component a knowledge of the stiffness factor becomes necessary. This factor is known as "modulus of elasticity." It is calculated from figures obtained from the load : extension diagram within the elastic range, using the formula :

$$\text{Modulus of elasticity} = \frac{\text{Stress}}{\text{Strain}}$$

Stress being the load in lbs. divided by the cross sectional area of the test piece in square inches. Strain being the extension in inches divided by the gauge length in inches.

Impact Test.

This consists of subjecting a notched test piece of standard dimensions to an impact blow produced by a falling weight. The two well-known types of machine used for this are the Izod and Charpy impact machines. The Izod machine is widely standardised in England, while the Charpy is extensively used in France and other continental countries. The impact resistance is measured in foot lbs. or kilogram metre units. The engineering specifications at present in use specify impact tests for steels only. The test is sometimes used for aluminium alloys for comparison purposes.

Hardness.

There are a wide variety of machines which are now used for this test, the most widely known being :

(1) Brinell Hardness Tester.
(2) Firth Hardometer.
(3) Vickers' Hardness Tester.
(4) Rockwell.
(5) Scleroscope.
(6) Herbert Pendulum.
(7) Herbert Cloudburst Tester.

The Brinell Hardness Tester and Firth Hardometer are similar in principle and they operate by impressing a hardened steel ball into the surface of the test piece by means of a predetermined load. The hardness number is obtained by dividing the load by the area of the impression. As the Brinell test uses a hardened steel ball as the indentor, it is not possible to use this test for measuring very high hardnesses, deflection of the ball itself taking place on very hard materials. The same remarks apply to the Firth Hardometer.

The Vickers' Hardness and Rockwell Testers use diamond indentors, the former using a pyramid and the latter a cone-shaped indentor. The Vickers' hardness numbers are obtained by dividing the load by the area of the impression in a similar manner to the Brinell Tester. The Vickers' machine may be used for all ranges of hardness, but it is particularly useful for the extremely high hardness values obtainable on case-hardened parts. A further advantage is is that the size of the impression is very small, and tests may be made on a working surface with little danger of damage.

The Rockwell machine measures hardnesses in terms of depths of penetration and a hardness numeral is automatically registered on a dial. The impression made by the Rockwell indentor is considerably larger than that produced by the Vickers' test, but on the other hand the test is a very much more rapid one and adaptable to quantity production.

The Scleroscope is a portable tester in which a small hardened ball is dropped on to the component from a fixed height, the hardness being determined by the height of the rebound. The Scleroscope test is useful for the exploration of large surfaces where variations in hardness are suspected.

The Herbert Pendulum consists of a beam which can oscillate on a centrally positioned hardened pivot. This balanced beam is placed on the specimen and allowed to oscillate, damping out of the oscillations being produced by frictional resistance between the hardened pivot and the specimen. A low frictional resistance and therefore low damping figure indicates high hardness, and conversely high frictional resistance and rapid damping effect shows low hardness.

The Herbert Cloudburst Tester is a very novel, but none the less valuable hardness testing instrument. It functions by the dropping of a large number of small hardened balls on to the surface of the specimen from a predetermined height. The surface is roughened by the balls to an extent dependent on the height of the drop and the hardness of the surface under test. By suitable arrangement of the height of the drop, the test can be made to pick out only the areas which fall below a certain standard of hardness. This method is valuable in testing large areas at one operation.

After the manufacturer has made his bars, tubes, stampings,

sheets, etc., and subjected them to the necessary treatments and mechanical tests, the material is then dispatched to the user who will machine or otherwise form it into the required components.

Raw Material Inspection.

In the aircraft trade it has been found necessary to introduce certain confirmatory checks on such raw material immediately on receipt from the manufacturer. While in a few cases complete mechanical tests, duplicating those of the manufacturer, are made, the bulk of the material is subjected to a few minor tests, simple in character, but chosen to give as much information about the condition of the material as possible.

The following examples will indicate the general trend of the test procedure.

Large important stampings such as crankshafts, crankcases, and connecting rods will have test pieces forged integral with the part. Complete mechanical tests are desirable on these parts. Visual examination of the forgings for surface defects, roaks, etc., will also be made, suspected areas being lightly filed or polished to reveal the defect more clearly.

Smaller stampings will have 100 per cent. Brinell hardness check. This test will help to pick out any stampings not quite to specification requirements and cases of wrong material. Also visual examination as above.

Bars will have 100 per cent. Brinell check and fracture test. It is advisable to make the hardness check at each end of the bar, as this will show variations in the heat treatment. The fracture test is also valuable in showing correct heat treatment and will also reveal defect such as roaks, central pipe, etc. Visual examination as for stampings. Bars which are supplied in the annealed condition for making components to be subsequently case-hardened, require to have samples sent to the heat-treatment shop for suitable treatment. These samples will be Brinell and fracture tested and checked against specification requirements.

Tubes will have a flattening and drifting test. The latter consists in expanding the tube at one end by forcing a conical shaped tool into it. The degree of flattening without cracking and the percentage increase in diameter produced by the drifting test, also without cracking, are valuable indications as to the satisfactory condition of the material.

Sheets have visual examination for surface defects and a flattening test on one corner.

Wire for valve spring manufacture requires very special attention. Tests made include the following :

(a) Visual examination for surface defects such as seams, roaks, and draw marks. This is supplemented by a pickling test on

a short length from each coil to reveal more clearly seams, roaks, etc.

(b) Tensile test and reverse bend test on each coil.

(c) Microscopic examination for internal defects and decarburisation of the surface.

(d) Winding test. This consists of close winding of a suitable length on a mandrel, afterwards pulling out to determine whether the wire is uniform in its characteristics.

It will be seen that tests made on spring wire are very exhaustive. The reason is that a valve spring operates under extremely severe conditions, so that quite small defects have a profound effect on its performance.

Castings are examined for porosity, draws, surface defects (such as trapped skin) and cracks. Cast test pieces, which accompany a batch of castings and are poured from the same pot of metal, are mechanically tested in the tensile machine.

Before leaving this description of raw material inspection, there is an aspect of the inspection of forgings which should not be overlooked, this is the question of grain flow. It is fairly well known that working of material by forging, rolling, etc., imparts improved properties to the material. This improvement is mainly apparent in the increased ductility and resistance to impact which the material receives. The greatest improvement is found when tests are made in the "longitudinal" direction, that is parallel to the direction in which the material has been made to flow. It is therefore important that the forging should be designed and worked in a manner to give a grain flow which will follow as closely as possible the contour of the finished component. Before bulk supplies of a particular stamping or forging are ordered, a sample should be sectioned for grain flow examination.

Machine and Formed Components.

This section deals with the last stage of material examination. The number of defects found in materials after machining should be very small, especially if the raw material inspection has been carried out satisfactorily. There are many cases, however, where defects are hidden under the surface and are extremely local, and in these cases only the machining operation will find them. It must be remembered also that where case-hardening is used, this operation is introduced after part-machining, and the application of the heat treatment operations involved, may tend to enlarge cracks too small to discover normally. The case-hardening operation itself may also bring in its train defects due entirely to the casing process. It would not be out of place here to refer briefly to some of the well-known defects of carburising, refining, and hardening, showing how they may cause rejection of part-machined or finished parts.

The following is a summary of case-hardening defects :

(1) Insufficient or too much case.

(2) Carburising at too high a temperature. This causes the percentage of carbon to be too high on the extreme surface of the case, inducing brittleness. This brittleness manifests itself in the form of cracking under running conditions. Also the fragility of the case is likely to make grinding of the surface very tricky and difficult.

(3) Incorrect refining temperature making the core low in toughness and ductility.

(4) Incorrect hardening temperature resulting in general softness of the case or local soft spots.

(5) Soft spots on the case due to components touching when entering the quenching medium.

(6) Another cause of soft spots on the case is local decarburisation produced by the furnace atmosphere.

Fault No. 1 is overcome by due attention to method of packing the parts in the carburising box. Also time and temperature of carburising should be investigated. It is ususal to place in the box with the component, a test piece, which can afterwards be fractured to reveal the depths of case.

Fault No. 2 can only be revealed by microscopic examination. This is not to be considered as a routine inspection method, since the defect should not occur in properly controlled and organised heat-treatment departments.

Fault No. 3 can be observed by fracturing a test piece which has accompanied the parts during the refining and hardening operations. A coarse crystalline-looking fracture indicates unsatisfactory refining.

Fault No. 4 is shown up by a test such as the Cloudburst Hardness test referred to previously. Another method consists in lightly etching the cased surface with dilute nitric acid in methylated spirits. The hardened areas are only lightly attacked, whereas the soft areas etch up much darker.

Fault No. 5 is revealed by the test methods described for No. 4. The trouble can be largely overcome by suitable spicing of the components on the quenching tray, and by not attempting to quench too many parts in one operation. Mechanical disturbance of the quenching medium is also useful.

Fault No. 6 is one which is not so serious on parts which are to be ground after hardening. There are cases, however, where it is preferable to finish the surface by a light polishing only. In these cases decarburisation presents a difficult problem. It can be overcome by covering the parts in the furnace by a thin layer of charcoal or carburising powder. Quenching from a molten cyanide bath is also a valuable alternative method.

Test on Finished Components.

Defects on finished parts may be grouped under the three main headings :

(*a*) Material defects (cracks, inclusions, porosity, etc.).

(*b*) Heat-treatment defects (particularly case-hardening cracks and soft spots).

(*c*) Defects induced by machining operations.

Referring to section (*a*) it will be apparent that the defects will be small in size, all large defects having been eliminated at earlier stages of the manufacture. In the case of porosity (a defect of castings), this may of course be revealed by the removal of the material in the later machining operations, and is checked by visual examination and pressure testing. Inclusions and cracks on components are not always easily revealed by simple visual examination. This is because they become lightly blurred over by the machining processes. There are two excellent methods for showing up these defects. The first consists in light etching of the surface with a suitable reagent. Among the many reagents which may be used, the following are typical examples :

Steels (other than stainless steels)—Two per cent. Nitric Acid in methylated spirits.

Stainless Steels—Twenty per cent. hydrochloric acid plus two per cent. nitric acid in methylated spirits.

Aluminium Alloys—Twenty-five per cent. caustic soda in water followed by a dip in 50 per cent. nitric acid in water.

Magnesium Alloys—One per cent. nitric acid in water.

The above etching media will show up non-metallic inclusions and cracks.

The second method of examination referred to is one confined to steels of magnetic susceptibility. The test consists in placing the part between two poles of an electro-magnet, and pouring over it a liquid containing iron dust in a fine state of division. Cracks are revealed by an accumulation of the iron deposit at the point at which the crack occurs. This test finds cracks of exceedingly small dimensions.

Referring to section (*b*) heat-treatment cracks and soft spots may be shown by etching, cracks also being revealed by the magnetic test describer above.

Defects induced by machining section (*c*) are mainly confined to grinding cracks on case-hardened parts. The cause of these cracks is local overheating of the material at the point of contact with the grinding wheel, producing differential expansion of the case material. The cracks are shown up by etching or magnetic test.

Some mention should be made of a manufacturing operation not covered by any previous description, namely, welding. It is not

often realised that when two metals are joined together by welding, the material in the vicinity of the weld is rendered coarse and brittle by the high temperature to which it is exposed. Failures of welded parts in service can often be traced to the presence of overheated metal. After welding the components should always be normalised, which means heating to a suitable temperature (dependent on the composition of the material) followed by air cooling. It is unfortunate that there is no suitable inspection method for this operation short of microscopic examination, which involves destruction of the part. Periodical examination of welded components, even if it involves the loss of an occasional part, is well worth while.

In conclusion, owing to the vast range of this subject, many of the inspection methods have only been lightly touched upon. A whole paper could, for instance, be written on "Brinell Testing." It is felt, however, that listeners would be more interested in learning of the wide variety of tests which are now used in engineering (particularly aircraft engineering) rather than a long description of one or two of them.

Discussion.

MR. KENWORTHY: I think you will agree that Mr. Gadd has given us a very interesting lecture. He has dealt with the subject from the ingot stage to the machined component and has given us the impression that the defects found in the final stages of machining were present in the ingot stage. That is a point on which I expect some of you may have something to say. I don't know whether it is due to Mr. Gadd being the speaker or to the nature of his paper, but I am very pleased to see such a large attendance here this evening. The subject is now open for discussion.

MR. ROBERTS: I should like to ask one question. You may have two connecting rods, with the same chemical analysis and the same Brinell hardness, and yet one machines much more easily than the other. Is that due to the extra working that one receives compared with the other?

MR. GADD: I do not think there will be a more difficult question asked me to-night. The machinability of materials is a most complex subject. In the first place machinability does not seem to have any definite connection with Brinell hardness or maximum stress. I remember a case in the works with which I am associated, where some material was very difficult to machine, although its Brinell hardness was only 180. After re-heat treating the material to give a hardness value of 320, the machine shop said that the machinability was then quite satisfactory. I think it is extremely likely that machinability may be connected with the structure of the material, and that this structure owes its characteristics to the original ingot condition, and to the degree of breaking down of the ingot structure by the forging operations. Variations in composition from point to point in the ingot and segregations of the alloying elements may also cause hard spots, making machining difficult. I have to confess that in spite of the great scientific knowledge that we possess in connection with material production, very little is as yet known on the subject of machinability.

MR. ROBERTS: It would appear that in spite of all our science and development we have still got to rest ourselves content with what we get. Very often in the course of working on sheet metal we find laminations. We write to the suppliers, and they reply apologising and blame the ingot makers. Shall we always have to rest content with that sort of thing?

MR. GADD: There is always a tendency to blame someone else. I am afraid I painted rather a gloomy picture of material defects, but my main object was to show that if the material was bad from the beginning, it could not be corrected by the subsequent working

operations, however carefully and expertly carried out. A tremendous amount of investigation into ingot casting is being done, and I think great strides will be made in this direction during the next few years.

MR. STONE: I have a small query regarding forged crankshafts. If after forging a crankshaft you then heat it to the normalising temperature and quench it in oil, will the normalising be as satisfactory as if it had been cooled in air?

MR. GADD: When a material has been hot worked the grain structure is often coarsened by the prolonged heating at elevated temperatures. The unsatisfactory structure can only be corrected by cooling down and then re-heating the part to its normalising temperature, which causes re-crystallisation to take place. The period of soaking at the normalising temperature should be short, otherwise grain growth will occur again. It is usual to cool in air after normalising. In the case of case-hardening steels, the refining operation is a form of normalising, but in order to obtain the best properties from the core, water or oil quenching may be resorted to.

MR. HIGGINS: I should first like to thank Mr. Gadd for his paper. He is certainly a master of his subject and knows it from "A to Z," and I think that after listening to him some of us will be able to say we now know it from "A to B" or even "A to C." I would like to ask what becomes of the residue of the ingot. Is it rejected or is it used in subsequent casts? From some of the chemical specifications I have seen some of the constituents are added in very small proportions. How are these proportions controlled, and are they added in solution in the metal or has the mix to be agitated continually?

MR. GADD: I must thank Mr. Higgins very much for his kind remarks. I am afraid I should have dealt a little more with the ingot side. I should have stated that 25 per cent. of the top part of the ingot is cut off and rejected for aircraft work, although, of course, it is extremely likely that it is melted down for other purposes. Five per cent. of the bottom part is also cut off, so that 30 per cent. of the ingot is absolutely wasted for aircraft purposes. We then hope that the rest of the ingot is sound, but there is still a possibility of an intermittent pipe which sometimes shows up in further operations.

In regard to the control of the material, I do not know that I am sufficiently able from my experience to answer your question very completely, except that the mixing of the metal is done in the melting furnace, and the various alloying elements are added in the form of alloys of iron, etc., and an extremely close control is effected. A certain amount of metal is lost in melting, but the makers are so expert that nowadays they can allow for the loss and

obtain very accurate figures. The figures given in the specifications show how closely they have to work. It is a very rare thing to find the chemical composition to be outside the specification limits.

There are some materials (lead bronze is an instance) in which the constituents are combined in the form of a mechanical mixture, no definite alloying taking place. In such cases continual stirring and rapid cooling is necessary to obtain a homogeneous alloy. In the case of steel, alloys of definite composition are formed, and while there is a tendency for some of the lower melting point constituents of the alloy to be pushed to the centre of the ingot, remarkable uniformity has been found when analytical checks have been made at various points of an ingot.

MR. HAWTHORNE: With reference to the hardness test, Mr. Gadd mentioned the Vickers' Hardness Tester. I have seen it stated on very good authority that this does not give a true measure of hardness. It does not take into consideration the piling across the edge of the diamond. In the Vickers' machine you read across the corners where most of the piling takes place, and I have heard it stated that this machine does not give a true reading.

MR. GADD: In reply to Mr. Hawthorne I should state that no hardness testing machine is perfect, but that each type has certain features rendering it most suitable for a particular hardness range. The Brinell test covers a very wide range of hardnesses and is considered to be one of the most reliable forms of hardness test. When we use it, however, to convert to equivalent tensile strengths, we find that there is no common factor suitable for all materials. This is partly due to fundamental differences in microstructure of different materials, tendency to work-harden, etc. In the same way the Vickers' hardness test is susceptible to local variations of structure and shows imperfect impressions due to minute differences in hardness and also to work-hardening tendencies. On the whole, however, I consider the Vickers' Hardness Tester to give the most reliable results over the widest range of hardness values of any hardness testing machine.

MR. SPENCER: Machinability is sometimes adversely affected by grain flow. Take the case of a metal with 0.4 per cent. carbon. Is it possible by any known heat-treatment to remove the adverse effects of grain flow?

MR. GADD: For all practical purposes, I should say no. It is impossible to remove the effects of grain flow by heat treatment. In some cases it is possible by extremely long terms of treatment running into hundreds of hours to break down the grain flow slightly, but with any normal heat treatment or treatment such as case-hardening, grain flow remains unaffected.

MR. HIGGINS: There is one type of test which has not been mentioned, the repeated impact test. Does not this show the

resistance of the material to fatigue ?

MR. GADD : The repeated impact test is not very widely used, because one cannot correlate the figures obtained with the static tensile test, as is the case with such fatigue tests as the Wohler rotary bend type. In the laboratory with which I am connected, we have a repeated impact machine, and we use it for solving definite engine problems where impact conditions occur. For example, we have found it useful for testing rocker attack parts and cylinder holding down studs, and in these cases stress concentration factors are very well brought out by this form of test. In short, the repeated impact test is a form of test applicable to special cases only and cannot be compared with other forms of fatigue test having much wider fields of application.

MR. HAWTHORNE : Does Mr. Gadd think that the very purity of metal may have some effect on the machinability. That is to say the purer metal is the more difficult to machine ? Are not impurities such as sulphur put into steel sometimes to ensure easy machining ?

MR. GADD : Mr. Hawthorne's statement is perfectly true. Free cutting steel, for instance, has a high sulphur content, and in general it may be stated that the lower the percentage of impurities, the more difficult machining becomes. The reason is that impurities allow the turnings to break up more easily before the tool, but as mentioned in my answer to a previous question on the same subject, variations in machinability are not completely explained by any simple factor such as hardness, tensile strength, or degree of cleanliness of the metal. The solution to the problem may be found in examination of grain structure, and this is largely influenced by the original ingot condition.

MR. BRAIME : The question I am going to ask is probably extremely elementary, but I do not know the answer. The lecturer showed us a table of mechanical tests giving figures with regard to the percentage reduction. Is that percentage reduction a reduction in cubic capacity or does it refer to some other reduction ?

MR. GADD : The figures referred to percentage reduction in cross sectional area.

MR. PINSENT : What allowance should be made on aluminium to ensure clean surfaces where machined free from holes ?

MR. GADD : I presume you refer to bar material. It depends entirely on whether the ingot has been suitably machined after casting, thus removing surface defects at the very early stages. If this has been done satisfactorily there should be little trouble from surface defects, except those introduced by the rolling operation (draw marks for instance). Machining of $\frac{1}{8}$ in. on the dia. may be sufficient to ensure a perfect surface.

A VISITOR: In the summary of the paper mention was made of the Herbert Cloudburst Machine, but the lecturer did not say anything about this.

MR. GADD: I had hoped to give a slide of the Cloudburst Machine, but as it is ten feet high or more it is difficult to photograph. The Cloudburst test has some very novel features and very valuable applications. The operation briefly consists in dropping a large number of steel balls from a predetermined height on to the sample under test. The test is used almost exclusively for case-hardened components and a large number of parts or a large area may be tested in one operation. If the height of drop is suitably selected the test will pick out soft spots on the surface, and these will be indicated by slight roughening of the material. The hard areas are unaffected by the test. The value of the test compared with the simple file test can easily be appreciated.

MR. TOPHAM: With regard to the flaw which the lecturer showed on the gudgeon pin, is there not any way of deciding whether these small surface flaws are dangerous or not? Some time ago we had some trouble with slight surface flaws on gudgeon pins and I believe we set up a standard with regard to them to enable us to decide to what extent they could be disregarded. It occurs to me that since then we may have evolved some method of deciding whether these flaws are dangerous or not.

MR. GADD: In regard to the question of inclusions on the surface of material, it is of course very difficult to set a standard for such defects when they occur on highly stressed components. It is reasonable to assume that if the surface under examination shows a large number of inclusions, the whole section of material is equally unsound. Equally, if the surface is very free from inclusions the whole section is of a high standard of cleanliness. Our standards of quality are therefore based on a superficial examination, and for gudgeon pins we say that there shall be no surface defects visible even with a hand lens. We do not delude ourselves into believing that because of this the whole section must be 100 per cent. clean, but we know it must, for reasons stated above, be very good in general quality. We know from experience that non-metallic inclusions, especially those occurring at the surface will cause points of stress.

A VISITOR: With regard to fatigue, take the example of the valve stem; does the inner structure collapse before the skin structure?

MR. GADD: In all cases excepting those where the material is case-hardened, fatigue cracks start from the surface. These cracks, although forming in this way, may in some cases be primarily due to internal defects or weaknesses, but the effect is to produce

general lowering in strength of the section, and the crack will start at the surface and spread rapidly towards the internal defect. In the case of case-hardened material, fatigue cracks very often commence at the junction of the case and the core.

MR. BUNTING: With reference to the Cloudburst Machine, I understood that that is now only used to make case-hardened surfaces more hard than they were originally.

MR. GADD: The primary use of the Cloudburst Machine is to test hardness. It so happens that it does work-harden the material under test and this feature has been made use of in certain instances. Soft materials are most susceptible to this work hardening, but case-hardened parts may also be slightly improved by the process.

MR. HIGGINS: I would like to know what effect the various machining operations have on the strength of the metal. In my early days we used to have a lot of what we called "green castings" lying about in the yard being seasoned. Can this seasoning now be done in hours? In the old days it used to take months.

MR. GADD: The structure of material is often very much deformed locally by the machining operations. The amount of damage done to the surface is dependent on the type of machining operation and the way the machining is carried out. It is interesting to note that as a result of recent experiments with "X" rays, it has been found that even samples very carefully prepared for micro-examination have residual stresses left in the polished surface, so that it is almost impossible to obtain machined components in an entirely stress-free condition. It is not very easy to estimate the ill-effect of surface strains on engine components, but it might be pointed out that tests of material, static, and fatigue are made on test pieces prepared by ordinary machining methods, and therefore should show the same proportionate lowered properties. In regard to the seasoning of castings, the effect of leaving them lying in the yard for several weeks was to relieve internal stresses, set up by casting, a long period of time at normal temperatures being required for this purpose. Nowadays the operation is speeded up by using more elevated temperatures and shortening the time to a few hours or even minutes.

MR. KENWORTHY: I must say that this paper has been very interesting to me because I am more or less concerned with material inspection, but I am particularly interested in the inspection of material in the final stages, and whilst Mr. Gadd has not dealt at great length with that point, he has shown how material defects originate in the ingot stage and persist right through to the finished component. Why is it that with all the advance of science something has not yet been done to find these defects in the ingot stage and prevent them passing through to the final stages. A development of X-ray examination may make

this possible. It strikes me that by that method of inspection the pipes and various other internal defects in the ingot could be found out at the ingot stage and the ingot scrapped if necessary, instead of going through many operations and finding out in the final stages that the ingot was faulty. One realises, of course, that even if the ingot is perfect, difficulties may arise due to improper working in the later stages. I assume that in a few years' time material will be more reliable. It may be costly to institute the necessary examination but for high grade material and for highly stressed parts the extra expense would be warranted if material could be thrown out in the early stages and the expense of useless machining operations avoided.

MR. GADD: In regard to Mr. Kenworthy's remarks, he is perfectly justified in saying that the technique of ingot casting should be better. I ought, perhaps, to have made it more clear that the list of defects described in my paper represents the very worst that can happen, and that in actual practice these defects do not, fortunately, occur so frequently as might have been imagined. There is undoubtedly a great deal to learn on the subject of ingot casting, and it may be of interest to mention that the Iron and Steel Institute have an Ingot Committee who are working very hard on this problem. Progress in engineering design, particularly aero engine design, has been extremely rapid during the last few years and, while improvements in technique of material manufacture have also been very marked, a great deal remains to be done yet in the way of improved quality of materials. I feel quite certain that great strides will be made during the next few years in the direction of better material quality.

THE APPLICATION OF TIME-STUDY TO ROLLING MILLS AND STEEL FURNACE PLANT.

Paper presented to the Institution, Sheffield Section, by P. Holmes, A.M.I.Mech., A.M.I.P.E.

IN spite of the fact that "time-study" has become a phase of common occurrence in industrial circles, there appears to be little understanding how, and to what extent, time-study can be of use to industry. It has often been said to me, "time-study is all very well for fixing piece-work prices, but what use is it in the heavy industries where the work is of a non-repetition nature?" In the following notes I have attempted to answer that question and to show how time-study can be applied with considerable advantage to the branches of industry with which we, in Sheffield, are familiar, i.e., rolling mills and steel furnace plant, etc.

Origin and Present Development.

In order to understand what we may expect from time-study, we must first consider briefly its origin and present development. It was first systematically developed by F. W. Taylor, the originator of "scientific management." He set himself the task of standardising the human element in industry, and in order to arrive at the proper standard, he instituted a system of time-study. His method was to divide work into its various elements and time them separately. The results were summed up and a percentage added for unavoidable delays, and called this the standard time. The results obtained by Taylor were not primarily due to improvements in the method of doing the work, but were due rather to shorter hours, the introduction of rest pauses, and various incentives to increased effort.

The work of Taylor was carried a stage further by Gilbreth, who, in addition to standardising the time, also standardised the method of doing a task. Without going into detail as to how motion studies are made, it will perhaps be sufficient to say that with special apparatus, the movements of the arms, hands, or other parts of the body whilst performing a given task can be recorded automatically. The aim of the motion study is to eliminate unnecessary movements, and by teaching the worker how to make every movement in the proper way, institute the best method for a particular operation. The work of Taylor and Gilbreth has been carried on by numerous other specialists in this study, to such an extent that

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to-day, particularly in the United States, almost every branch of industry has made use of the services of " management engineers."

It will, no doubt, be of interest at this stage to review briefly the position in Germany to-day as regards " time-study." The necessity for increased efficiency in the industrial enterprises had long been recognised. It was not until some time after the war, however, that any practical measures were taken towards a solution. A committee (A.W.F.) was formed to devote its attention to the problems involved and the fact that experts came in large numbers from all parts of the country to attend the meetings of this committee in Berlin, made it clear that the work being done was one of the most important elements in the economic and industrial reconstruction of Germany.

An organisation called the " German National Committee on Time-Study " was set up for the purpose of collecting all available material bearing on the question of " time-study." This material was sorted out and made available to the public in a form suitable for references and as a basis for special instruction courses. The National Committee formed " Boards " throughout the country for the organisation of instruction courses and in four years 115 such instruction courses were held in 45 German towns and 5,000 time-study observers have been trained. This has meant the acquisition by German factories and workshops of a vast amount of knowledge in the field of scientific management.

As the movement developed the number of instruction courses were increased to meet the requirements of the special branches of industry. Seeing that the basic principles are such that they can be applied to any branch of industry, it is not surprising to find that the work done by the National Committee has had such an influence, not only on the iron and coal trades but on the textile, rubber, and porcelain industries and even agriculture and forestry.

During the past few years, numerous papers have been published on the subject of time-study in connection with the various branches of industry previously mentioned. It is of interest to note that these papers have emanated from the Continent or America, and in no case have I come across a paper written or published in this country, excepting two papers that were read before the Iron and Steel Institute in 1931, which were translations of papers issued in Germany.

There have been, however, numerous papers read before the various societies and institutions of this country and particularly before our own Institution, but in most cases, these papers have dealt with time-study as a means of determining a basis for the fixing of a payment in some form or other. It is not time-study that deals with individual operations that I refer to in my remarks, but to the application of time-study, to a complete unit of a given

plant, where payment is not considered and where individual operation times are enveloped in the complete cycle time for the whole process.

Time-study of the nature just referred to is practically unknown in this country. One of the reasons given for this, is the hostile attitude of the workers' organisations. Now where a study is made, say of a rolling mill or furnace plant, the question of wages does not enter, and a workman appears on the observation sheet as a mere number or other symbol. Therefore, it is difficult to see where there can be any cause for opposition from the workmen or their societies. Another reason would probably be found if we considered the cause of lack of interest of the higher authorities who control the industrial organisations.

A stop watch in the hands of the wrong type of person can be a very dangerous instrument. To illustrate what I mean I will tell you the story of the "Boss" of a privately-owned concern who had read a little about time-study and bought himself a stop-watch. He fixed a piece-rate for a certain job and the men earned time-and-a-quarter. A little time after, he thought the men had a soft job so he cut the allowance by a quarter, but the men still earned time-and-a-quarter, so he again cut it by a quarter, but the men still earned time-and-a-quarter. After that he thought he had cut enough and would probably have left it at that if one of the men who was leaving for another job had not told him that if he cut the price again, the men could still earn time-and-a-quarter.

Time-study is not, as most people think the mere timing of a job, and if the people responsible for this crude guess-work could only be made to realise the discredit that is brought to time-study in any form, then they would leave such work to engineers who have the knowledge and experience of the technique of performing an intensive investigation.

The Application of Time-Study.

A time-study covering the whole of a department or section of a plant, not only presents an accurate view of the process as already carried out, but is a means of predicting the effect of any proposed change. If, in the many separate processes which together make the complete manufacturing process, it is found that a particular process is below or in excess of the average strength, then this means that there is a waste somewhere. The maintenance of an even output capacity may permit a reduction of capacity at one point or require means of an increase at another point.

Before an even balance of production can be obtained, it is necessary to have an accurate knowledge of the actual and possible output of each unit. This is not easy to obtain since all work consists of actions and delays, the actions being partly productive

and partly wasted effort and the delays may be in some cases necessary. Comparisons of periods of time without the aid of instruments are, to say the least, unreliable, and the rapid succession of actions and delays presents too varied a spectacle for the human eye to grasp in its true proportions. Time-studies, however, present a means by which events may be recorded accurately as they occur and by which a large number of observations can then be analysed and tabulated to give a number of facts upon which conclusions may be drawn. The information obtained often leads to the modification and even the reversal of impressions based on casual observation. Cost accounts, progress planning, etc., have, of necessity, replaced the old rule-of-thumb method, and in the same way casual observation must be replaced by accurate knowledge in all matters concerning methods and appliances for securing greater manufacturing efficiency.

All industries do not lend themselves equally well to time-studies, but it will no doubt be agreed that it is in the industries where operations do not always occur in an identical manner, and in the same order, that time losses are greatest, and here, even though split-seconds are seldom recorded, a time-study makes it possible to draw important conclusions in a very short time.

With regard to the actual application of time-study, it is exceedingly difficult to say how a time-study in a given department shall be made. There are many variables that must be considered before the actual method of carrying out the time-study can be decided upon. The number of observers required will depend upon the number of divisions into which the complete process can be subdivided. It is best to arrange that the duties of any one observer are such that he has sufficient time between the recording of each incident to enable him to make general observations and notes. It is better to have one spare observer, who is not tied down to recording, but is free to co-ordinate or even relieve other observers in the team. Depending upon the nature of the work, the number of observers may vary from two to twenty.

It will be found that when a study has been commenced it is best to continue it throughout the whole of the time, to the end of the period which may be the closing down of that department for the week-end. For instance, where the work is continued round the clock, a study made on "days" only will not give a true record. It sometimes happens that a particular operation must be timed independently by two observers, that is, a particular incident will be the last recorded time for No. 1 observer, but will also be the first recorded time for No. 2 observer. By this method the time of the day shown by the various watches in use can be kept to the

same standard and is also a means of eliminating the possibility of any time between the finish of one incident and the commencement of another being left unaccounted for. The method of timing will again depend upon the operation being observed. In some cases each operation or interval can be recorded as so many seconds' duration without regard to the time of the day at which each incident occurred.

With regard to the observation sheets (by which is meant the paper upon which the records are made), it is very difficult to fix upon a standard which would suit all jobs. Only in the smaller departments of the plant where definite articles are made in a recurring manner is it possible to use a standard observation sheet.

A good plan to adopt when a study is about to be made is to first of all become acquainted with the general working of the department, noting the connections between one operation and another. This will give some idea as to how many observers will be required. Next allocate the duties of each observer and make a preliminary study of one or more days' duration. The results thus obtained will enable a definite scheme of working to be prepared and also will enable the type of observation sheet which will be used, to be set out, giving the necessary headings to each column. It will be found that it is more convenient to make the records on loose sheets rather than in book form; the advantage of this will be found when it comes to comparing the various observers' sheets when analysing the results.

With regard to the type of watches used, this will again depend on the class of work being observed, but generally speaking it will be found that the watch with a large dial (22 line size) about two inches diameter, divided into minutes and decimals, is more convenient than the smaller watch showing minutes and seconds. With either type of watch they can be obtained having a "Stop-Flyback" action with one or two fingers, or "Stop-Go" action giving continuous readings. In addition to stop watches, there are several instruments available which enable a record being made of the times of various operations by one observer. These are of the type whereby several pens act on a moving paper chart and are operated by means of push buttons.

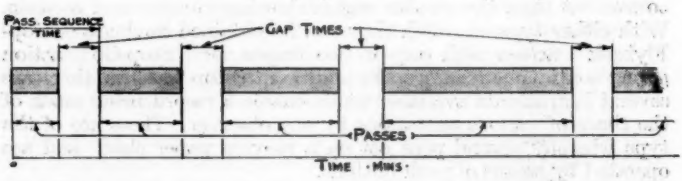
One of the aims of a time-study is the determination of the best performance possible, that is, the highest possible production of goods in a certain department. To obtain this, we must first determine the narrowest section of the plant, or, as it is sometimes called the "bottle neck." By this is meant the section of the plant where the piece passage time is greater than it could be in any other part of the plant if this section is considered separately and apart from

the others. In numerous cases, it is generally known without special observation, what part of a plant or what process in this part shows the narrowest section. In these cases, the piece passage time can be measured directly, but an extensive study becomes necessary when it is required to know how results will go, because with the removal of the former "narrowest section," another often arises in another place, and where this will be, and what passage time will be the result, cannot be forecast.

Many time-study engineers try to solve the problem by finding where one process has to wait for another process, in the belief that waiting times hinder production or at least point to bad organisation. This, however, cannot be taken as general; there are cases where the passage time is shortened by the introduction of waiting times. Waiting times on machines and auxiliary apparatus denote wrong organisation, or that the plant is not being used to its full capacity. Waiting times of workmen have no particular significance for the attainable passage time, without further investigation. Times during which the material is kept waiting may occur when the passage time is reduced to just below the shortest time possible. Therefore, if passage time is reduced until waiting times occur for the material, that the actual capacity can be obtained, but not the reason for its limiting. The most difficult part is the determining of the causes to which waiting times may be traced.

The best method of presenting the results of a time-study again depends upon the class of work being observed. Generally, it is best to extract from the observation sheets the essential facts and present these in the form of coloured charts in a manner that will

PRODUCTION CHART



SEQUENCE OF PASSES

IN CASE OF REVERSING MILL 2 HIGH OR BACKWARDS & FORWARDS 3 HIGH.

Fig. 1.

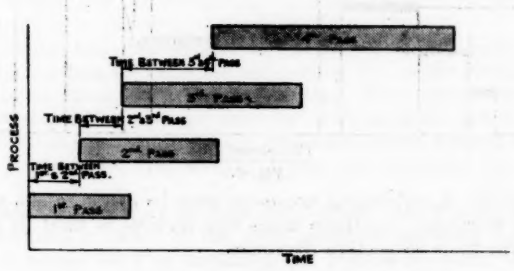
show clearly and at a glance, the points which it is desired to emphasise.

The following charts are shown as examples of the various methods of presenting time-studies.

CHART No. 1 shows pass sequence, roll contact, and gap times. In case of reversing mill (2 high) or backwards and forwards (3 high).

CHART No. 2 is similar ; for a continuous mill, i.e., where a pass can begin before the preceding pass is finished.

PRODUCTION CHART



METHOD OF WORKING WHERE A PASS CAN BEGIN BEFORE PRECEEDING PASS IS FINIINISKED i.e. CONTINUOUS MILLS

Fig. 2.

PRODUCTION CHART

SECONDARY TIMES NOT SUBDIVIDED

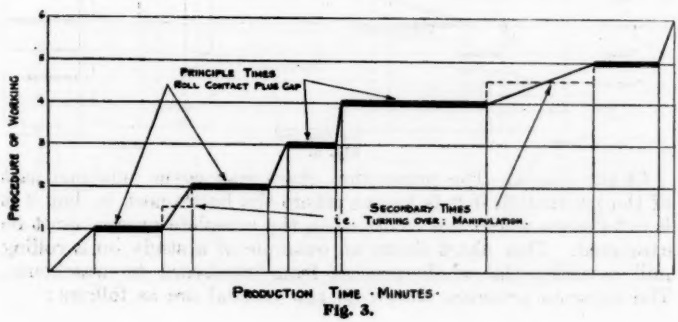


Fig. 3.

CHART No. 3.—This chart can be used for several cases. As an example, the successive trains of rolls for the complete manipulation of an ingot. The vertical shows the separate processes whilst the horizontal shows the time taken.

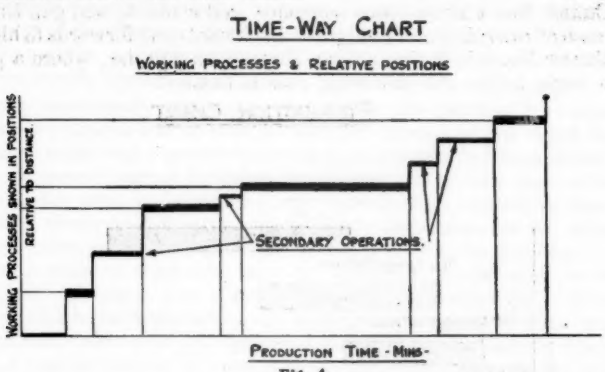

TIME-WAY CHART
WORKING PROCESSES & RELATIVE POSITIONS
WORKING PROCESSES SHOWN IN POSITIONS RELATIVE TO DISTANCE
SECONDARY OPERATIONS.
PRODUCTION TIME - MINS -

Fig. 4.

CHART No. 4.—Working processes may be synonymous with the place of working. In these cases the vertical is used to indicate places and their respective distances.

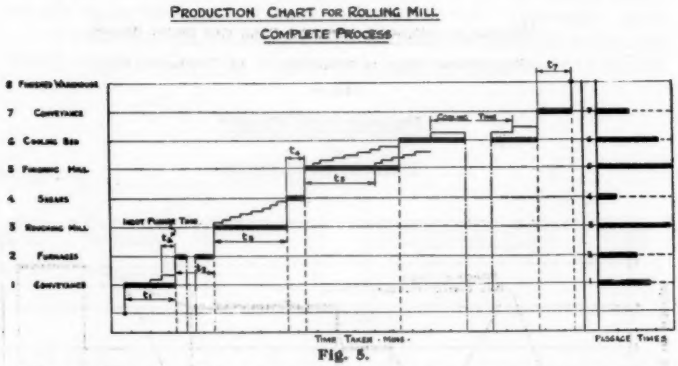


Fig. 5.

CHART No. 5.—The production chart may cover only one part of the production if it is known where the bottle-neck is, but if it is not known where this exists, then the complete process must be examined. This chart shows an example of a study on a rolling mill covering the whole process from stockyard to warehouse. The separate processes shown on the vertical are as follows :

(1) Conveyance (ingot bogie). The ingot passage time is the bogie time divided by the number of ingots on the bogie. If it is suspected that the bottle neck lies here, then special surveys should be made on this part and the separate processes examined, even down to the passage time of the ingot pusher.

(2) The passage time of the furnace, if considered separately, is the shortest heating time divided by the number of ingots in furnace.

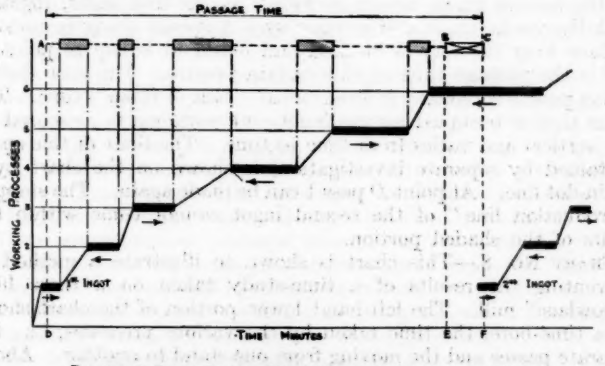
(3) Roughing mill. In this case two ingots cannot be in the mill together. Therefore, the passage time is equal to production time.

(4) Time at shears equals t4.

(5) Passage time in finishing mill, t5. The production time is actually longer, but the second ingot can be commenced before the previous ingot is finished.

(6) Cooling bed, t6. Whilst this is shown as the longest part operation, the passage time for the cooling bed is the cooling time divided by the number of bars on the bed. The right-hand part of the chart shows the passage time for each separate operation It will be noticed that the finishing mill time is the longest and for the other processes, the waiting times are indicated by dotted lines.

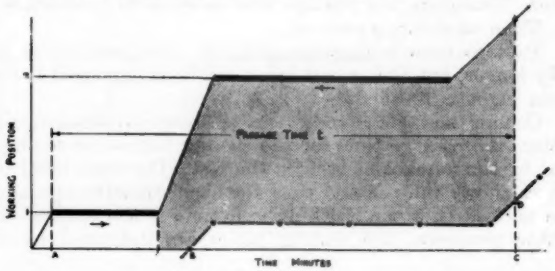
The passage time may be dependent upon : (*a*) The time which each individual member of the crew needs for his work, and may consist of actual work or watching the process of work, or may consist of time during which he is getting ready ; (*b*) the time which auxiliary apparatus (cranes, manipulators, lifting tables, etc.) need for their work. These may actually be in motion or occupied by the material.



Example of Finding Passage Time From the Occupied Time of a Workman.

Fig. 6.

CHART No. 6 gives an example for the determination of passage time by the working time of a man. The man is behind the rolls. This activity begins at point *D*, i.e., whilst the bar is still in the rolls. He deals with the bar until he has seen that it is running straight in pass 6—point *E* and returns to his original position, and waits ready to take the next bar coming through pass 1. This time will be *EF*. *DF* is the passage time for the workman. The actual employed time is shown dark, and watching times shown dotted. The cross shows the time taken in returning to his original position.



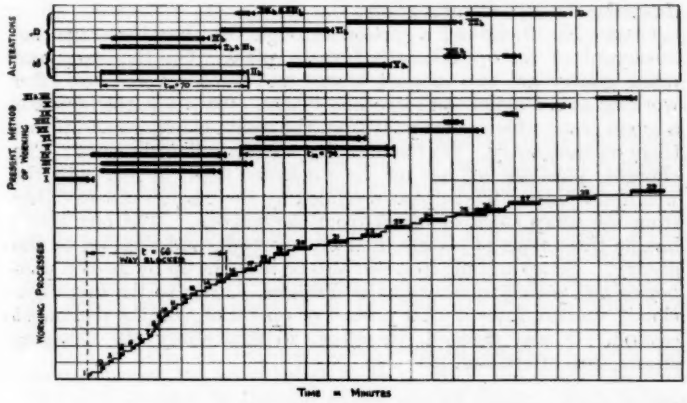
EXAMPLE FOR FINDING TIME LOST BY WAY BEING BLOCKED.

Fig. 7.

CHART No. 7—SPACE CHART.—It sometimes happens that "available space" is the determining factor. The chart illustrates a typical case. After pass 1 of the first ingot or bar to the time *B*, the second ingot cannot be rolled, as the first ingot, together with the workmen, is still in the way. A special study is made as to how long the way is blocked and found to be up to point *C*. *AC* is the passage time of this certain process. The time during which pass 1 is blocked is often called "lack of room" time. The room that is occupied by the ingot and workmen is measured on the vertical and varies from time to time. The limit of this space (obtained by separate investigation) is shown on the chart by a chain-dot line. At point *D* pass 1 can be made again. The stepped "production line" of the second ingot cannot come within the limits of the shaded portion.

CHART No. 8.—This chart is shown to illustrate a method of preventing the results of a time-study taken on a three high "Dowlais" mill. The left-hand lower portion of the chart shows on a time-bore, the time taken by the various processes, i.e., the separate passes and the moving from one stand to another. Above this has been drawn a graph showing the occupied time of each workman on the same time-base. From this is developed the

"passage time" for each workman. It will be seen that the "piece passage time" is 0.74 minutes, and is determined by the occupied time of workman No. 5. This man takes hold of the bar



STUDY ON DOWLAIS FINISHING MILL

Fig. 8.

from No. 3 workman and finishes when the bar is running straight in pass 23. Workmen Nos. 8 to 12 have very little to do, and in this case where the men are of decisive importance, tests were made to see if work could not be better distributed amongst them.

With alteration (*a*), it was found that by using 11 men as against 12 originally, the piece passage time could be reduced from .74 to .70 minutes.

With alteration (*b*) the passage time was reduced still further when 13 men were used in the mill. With this method of working, the passage time of workmen 2*b* and 3*b* is less than the longest time during which the way is blocked. This "blocked way" is caused by the workmen standing in the way behind the rolls until pass 15 is made. There is no object, therefore, in further shortening the working time until the "blocked way" time can be reduced.

There are numerous practical conclusions which can be drawn from this graph. Up to the present the ways in which the "narrowest section" can be found have only been dealt with. In every case, the "narrowest section" is found at the point where the longest passage time exists and may be any of the following:

(*a*) A working process (principal time).
(*b*) Transference from one place to another (secondary time).
(*c*) Times of workmen.

(*d*) Times of auxiliary apparatus.
(*e*) Lack of room or waiting time. Or
(*f*) Recovery times which are necessary to a machine.

(*The author next showed a set of charts dealing with an attempt to determine the capacity of a plant.*)

CHART NO. 9 showed a section through the charging stage and stockyard of an open hearth furnace plant. On the stockyard crane gantry are two magnet cranes and one converted box lifter working as a magnet, and two box lifters. On a separate track is a mono crane which takes pans from the weigh machines and places them on the gantry. On the charging stage are five chargers. The charging pans are set out on the stockyard floor, in line with the weigh machines. These pans are filled by the magnet cranes either from the scrap stock or direct from the wagons. The box lifters handle three pans at a time, first on to weigh, and then on to the gantry. Scrap and pig-iron can also be brought up by loco on pan-bogies and placed in front of the furnaces. Prior to the investigation it was not known what process or operation was the narrowest section. It was decided, therefore, to time-study the charging cranes, box lifters, and magnets.

Charging Cranes.

Twelve complete charges were observed. Taking into account the different distances between the furnaces and the various possible position of the pans on the gantries or pan bogies, it was found that the average time for 863 pans was 1.18 minutes per pan. Allowing for meals, delays, breakdowns, etc., the five machines could handle per week, 27,000 pans or 254 pans per hour. For every ton of ingots there requires to be charged into the furnace, 25.7 cwts. of material, or the charged material is 1.3 times the ingot tonnage. The average weight per pan (including pig iron) is 20 cwts., therefore, for an ingot tonnage of 11,000 tons per week, the chargers would be required to handle 134 tons per hour. This gives a reserve charger capacity of 52 per cent. on 11,000 tons basis for normal working, but does not cover periods where more than five furnaces are charging together. Obviously the narrowest section does not lie here.

Box Lifters.

Eight complete shifts were observed on these cranes. The cycle of events includes picking up from stockyard, weighing, place on gantry, release of pans, pick up empties and set down in stockyard. The number of pans brought up during observed period was (three pans at a time) 1,008 or 336 lifts. It was found that each box lifter could bring a lift (three pans) on to the gantry in 6.72 minutes

or 2.24 minutes per pan. This represents the piece passage time for the box lifters.

Magnet Cranes.

CHART No. 12 showed the average working periods and delays for the three cranes. The average time per pan during the pan filling period was found to be 2.34 minutes.

Box Lifter Capacity.

A study of the prevailing conditions showed that it was impossible for the crane to work at anything near 100 per cent. of their normal working periods. At the beginning and the end of the week, several furnaces require charging together. This means that there are periods when the box lifters have no work and also causes cranes to obstruct each other. A working efficiency for the stockyard cranes had to be assumed and from a knowledge of the extent of the delays this was fixed at 80 per cent. for the box lifters and 70 per cent. for the magnet.

With a view to checking these assumed figures, a chart was made representing an attempt to reconstruct the conditions from 10-0 a.m. Sunday to the end of the second charge. Each furnace gantry could hold 18 pans, and it was accurate enough to take it that both the box lifters and magnets could handle 18 pans in forty-one minutes. The standing periods for the box lifters was found to be 30 per cent. and for the magnets 27 per cent. It will be appreciated that with theoretical work such as this, the figures are on the favourable side, as with fore-knowledge of the charging times and sequences, arrangements can be made which are impossible in practice. The weekly working period (excluding meals) is 113 hours which, at 2.24 minutes per pan, gives 9,080 pans per week. Taking the average weight per pan to be 17 cwts. and assuming 3,000 tons to be brought up by loco, the box lifter capacity in terms of ingot tonnage is 8,252 tons of ingots.

Magnet Crane Capacity.

Allowing an efficiency of 70 per cent. on account of obstruction by box lifters, unloading into stock, etc., the hours worked is 98.7. Three cranes, working at 2.34 minutes per pan, gives 7,592 pans, which, at 17 cwts., each represent 6,453 tons. Allow 3,000 tons brought by loco and also one-sixth of the material such as lime, scale, etc., being manhandled, then the magnet crane's capacity is 8,106 tons of ingots

We have up to the present obtained the passage times for the three chief processes, i.e., charging cranes 1.18 minutes, box lifters 2.24 minutes, and magnet cranes 2.34 minutes. This, however,

does not determine by what causes the capacity is limited, but from notes made by each observer and from a detailed examination of all the observation sheets, the reasons can be found.

The cranes obstruct each other when fetching lime and scale or when travelling to the weigh machines. These are only a few of the many causes of delay but they are sufficient to show that the limiting capacity is due to the fact that with five cranes on the same track, doing two operations the individual passage times are higher than would be the case with a different disposition of the cranes and their work. It was calculated that with an extension of the mono crane track and an additional mono crane, the box lifter efficiency could be increased to 85 per cent., giving an increase in shop tonnage of five per cent. It was further calculated that by converting another box lifter into a magnet and the provision of a further mono crane, the shop tonnage could be increased to 10,000 tons.

Another advantage to be gained from a knowledge of piece-passage times is the ability to forecast requirements. As an example, take the question of charging pans. The shortage is particularly pronounced on Sunday noon when several furnaces are likely to charge at the same time. In many cases 26 pans are required for the first part of the charge, and seeing that the gantry can hold only 18 pans, then to avoid delay a reserve of eight pans should be filled before charging commences. The bringing up of these eight pans and the removal of the other 18 pans will take the box lifters $26 \times 2.24 - 45$ minutes. The 26 pans can be charged in thirty minutes, after which a period of, say, forty minutes must elapse for melting. At the end of this time, further pans will be required but the magnets will only have been able to fill 17 pans. It is probable that 20 pans will be required and so the difference, three, must also be ready before charging commences. In this particular case, using these assumed figures, it will be seen that the number of pans required per furnace is $18 + 8 + 3 - 29$ pans. This does not include the pans occupied by feed, which is usually about eight. A further use for the passage times is in the preparation of a Nomogram.

It is not always the case that a time study is made for the express purpose of finding the piece-passage times. In many instances, the result of a detailed study enables the whole sequence of events throughout the various operations to be visualised. From the records made, charts can be prepared which will show the exact happenings at any given time during the observed period.

A request was made for information as to what happened from the tapping of a furnace to the arrival of the ingots in the soaking pit furnace. To make the study complete, it was necessary to commence observations at 10-0 a.m. on the Sunday and continue

throughout the whole time until the following Saturday evening.

There were five observers on each of the three shifts. This is mentioned to show the difference between one man timing an operation for ten minutes and a real comprehensive time study.

As can be imagined, a vast amount of information was obtained but the difficult part was to analyse the results and to present them in a suitable form.

A study of events occurring in the melting shop during the first twelve hours of the week gave the impression that progress was being retarded by a shortage of casting cars. This apparent shortage is aggravated by : (*a*) nine furnaces tapping between 2-0 p.m. and 5-30 p.m. and, not knowing the sequence of tapping, every pit must be set in readiness ; and (*b*) a number of cars occupied by moulds and bottom plates which are required for the second round of tapping. A chart was made showing the disposition of all available cars prior to the first tap together with the times of teeming, stripping, arrival, and departure from soakers for the complete first round of tapping.

The charts have been shown to illustrate the methods of presenting the results of time studies. It is obvious that in a plant where several shops do work of a similar nature, the charts must, of necessity, be similar also. The studies referred to were made some considerable time ago and so it is hoped that no one will compare the results, or tonnage, with present-day practice.

There is a general impression that the engineering industry has been the main field of time-study. The system is not limited to engineering manufacture or even to manufacture in general, and, whilst the subject has been limited to-night to rolling mills and furnace plant, the system has been applied to almost all branches of the heavy industries.

One objection to intensive time-study is the cost ; but the efficiency of a plant cannot be judged by the ratio of its overhead to its direct charges ; the only criterion is the total cost of the product.

Time-study observers should be organised under a single control directly responsible to the works management and not under the department to which they may be allocated. This entails that the time-study engineer has not executive authority, and can only make recommendations. In conclusion, I would add that no management can carry on its duties without information as to what is going on in the works ; and time-study is the only trustworthy source of some of the most important of this information.

THE MANUFACTURE OF ELECTRIC MOTORS.

Paper presented to the Institution, London Section, by G. H. Fletcher, M.I.E.E.

I THINK it is important in introducing this subject to make it clear that the factory in which I am interested is a specialised factory manufacturing a type of motor for special service, and I think that in order to appreciate what I have to say regarding the manufacture of motors, it is important to give a little consideration to the product. This factory has specialised for at least fifteen years in the manufacture of motors for traction purposes, that is, railway motors, tramway motors, and trolley bus motors, with the necessary gearing and also auxiliaries for traction, such as motor-generators, compressor motors, fan motors, etc. In addition we manufacture main line, shunting, and mining locomotives, and diesel electric locomotives.

The service, for the main motors particularly, is extremely arduous. In the first place the majority of the motors are mounted directly on the axle, and are therefore subject to all the shocks which are transmitted from the wheels due to impact on the rails. In the second place, they are out of sight and cannot in practice be examined during operation. Thirdly, a breakdown on such a motor may hold up train service, or may have much more disastrous results. Under these circumstances, therefore, the quality of workmanship is higher and the amount of inspection and testing much greater than is necessary with the industrial type of motor, and an organisation which is set up to deal with the manufacture of motors of this class must have these points well in the forefront.

Originally in our organisation the traction motors were manufactured along with the industrial motors, but this was found to be rather unsatisfactory from a manufacturing point of view, and it was considered advisable to keep this class of work entirely separate from industrial work. Traction motors cannot in the true sense of the word be mass produced. Because of all the many variations in gauge, wheel diameter, voltage, etc., it is very rarely on railway work that the same motor may be used for several jobs. Orders may be received in quantities of from 500 to 600, and therefore a considerable amount of tool development can be justified and in many cases the machine tools may be set aside and retained for one operation.

London, January 4th, 1935.

In my view it is essential that the designer of the apparatus to be manufactured should be in the closest posible contact with the work, and should therefore be located on the same premises. This is essential from two points of view. In the first place it is essential that the designer should be familiar with the plant and machine tools with which the apparatus is to be built, and during the laying out of the design should keep in the closest possible contact with the tool department and the process department with a view to minimising tool costs and manufacturing costs. In the second place questions which may arise during manufacture and which come up for decision by the designer cannot be satisfactorily settled by correspondence or occasional visits or by telephone, but only on the job itself. Incidentally it is just as essential that the designer should be in the closest possible touch with the service conditions, and should make contact with all the difficulties which may be experienced in operation.

Organisation.

Our organisation is controlled by a general manager who is responsible for both the design and manufacture, reporting to the director of manufacturing and the director of engineering for the company.

The engineering department is controlled by the chief assistant engineer who also controls the drawing office through the chief draughtsman. The estimating department is under the control of the chief estimator, who reports directly to the chief engineer and manager. The branch accountant is responsible for wages, costs, shipments, invoices, etc. The works department consists of the following, all of which are under the control of a superintendent, who is directly responsible to the chief engineer and manager, who controls the whole of the works organisation, including engineering and tendering.

Production Department (under chief production engineer).—This department controls the manufacturing programme of the works, and is responsible for the obtaining of all materials and information necessary to enable manufacturing departments to meet shipment dates given to customers.

Purchasing Department (under chief purchasing agent).—This department is responsible for all material and goods required from suppliers outside the company's own factories, that is, makes purchases on instructions issued by the production department on information received from the engineering department.

Stores Department (chief clerk in charge).—Responsible to production department for keeping stocks of material available, in accordance with instructions issued by production department

from time to time to suit work on order and going through shops (manufacturing departments), and for the issue of materials to manufacturing departments. Also, for keeping available supplies of all kinds of materials required for running and maintaining works plant. All materials received from outside are received by them and recorded.

Process and Rate Department (under chief process engineer).—This department is responsible for giving labour and factory expense figures to the engineering estimating department. They are also responsible for putting into suitable form for issue to manufacturing departments all information and instructions issued by engineers and drawing office departments. Also, for the fixing of piece work prices and the class of labour to be used for various classes of work.

Works Planning and Jig and Tool (Drawing Office) Department (under chief jig and tool draughtsman).—This department is responsible for the layout of works plant, and the provision of suitable machine tools and other apparatus necessary for the various manufacturing departments to carry out the operations required on the products going through the works. Also, for the design and manufacture of the jigs, tools, and gauges required by these departments.

Maintenance Department (foreman in charge).—Responsible to planning department for keeping all works plant in satisfactory running order.

Inspection Department (under chief inspector).—Responsible for inspecting all materials coming into works (in collaboration with research department), and for the inspection of all parts going through manufacturing departments, and for finished products going into shipping department, and for the standard of work turned out generally.

Testing Department (under chief tester).—Responsible for the testing and satisfactory performance and output of all apparatus before sending to shipping department.

Manufacturing Departments (under foreman's control).—Foremen in charge of departments report directly to superintendent. Each foreman is provided with one or more assistants according to size of department, and also with one or more clerks who are responsible for the issue of job tickets to workpeople, inter-departmental shipping notes, record keeping, filing, and general departmental clerical work.

Shipping Department (under chief shipping clerk and foreman packer).—Responsible for the dispatch of all apparatus sent out from the works, suitably packed for any destination. Packing cases made by packing department to meet requirements and conditions, particulars of which are issued by chief shipping clerk.

Labour Bureau (chief wages clerk in charge).—Responsible for obtaining supplies of labour, and keeping records of suitable

applicants. Foreman must receive sanction to introduce new labour from superintendent, who also decides the grade of labour for any particular class of work. He then makes application to the labour bureau for labour required, who then obtain suitable candidates and submit them to foreman for final choice. In special cases, choice is made by superintendent.

Education Department.—This department is responsible for all apprentices entering the works, whether trades, school, or college. In each case an examination has to be passed to ensure the requisite standard being maintained for each grade. A register is kept by Labour Bureau of Trades Apprentices, and these enter the works as required on the decision of the superintendent. On entering the works they are fathered by the education department, as regards their technical training and progress through the various works departments. A programme is formulated and boys are moved to this as far as work in hand will allow, and having due regard to the progress being made by each individual. Lectures are given during working hours by members of the education department's staff. School and college apprentices are treated specially by the education department and management, the works superintendent having little say in the numbers taken at any time.

Welfare Department (under welfare supervisor).—Responsible for ambulance work and first aid, canteens, and dining rooms ; cleaning staff and welfare of female labour particularly.

Cost Department.—The question as to how far a costing system should extend is one which should form the subject of considerable discussion. I have known of some large manufacturing plants in which the costing is of the most elementary nature, in fact almost non-existent ; and in others in which the system is very elaborate and in itself quite an item of expense. The objects of a costing system are :

(1) To assess and allocate to the manufacturing plant either to individual machines or the factory as a whole, charges other than the productive labour charges designated factory expenses, factory charges, overhead charges and cost, etc.

(2) To obtain from bookings to a job the actual cost of an order with a view to comparing with the estimate.

(1) The method of charging factory expenses in our factory is to give to each machine an hourly rate. This is assessed upon the following factors : Floor area, power used, consumption of cutting tools, interest, depreciation and maintenance. The items of expense which go to make up the total are divided for convenience into three classes ; designated Classes A, B, and C expenses.

Class A Expenses.—These are expenses which may be controlled to some extent by the foremen, and consist of the following items : Miscellaneous labour and material, maintenance of machines, small

tools and other plant, defective workmanship, departmental supervision, such as charge-hands, inspectors, and others; classes over which the foremen can exert some control.

Class B Expenses.—Are those which are largely outside the jurisdiction of the foremen, but are controlled by the superintendent. These comprise: Power, steam, gas, maintenance of buildings, furnaces, etc.

Class C Expenses.—Under this heading is brought together charges including depreciation and salaries to office staff, etc.

Having obtained the total expenses of the factory a certain budgetted output is assumed requiring X bench, Y service, and Z machine hands. Certain items of expense are assumed for the bench and service labour, and these are divided by the budgetted output number giving the hourly rate for hand and service labour.

For the machine tools, certain items such as standing charges, lighting, heating, etc., are allocated in accordance with the floor area occupied by the machine and its operator. To this is added certain other charges incurred by the machine itself such as power, interest, depreciation and maintenance of machine and cutting tools, etc.

(2) In addition to obtaining the actual cost of an order, a cost analysis is often of the greatest value. Not only is it a check on the original estimate, but in the event of a discrepancy between estimate and cost, by a segregation of the cost of the different operations, the discrepancy can be located and may be found to be due to some cause which might otherwise be perpetuated. Or a discrepancy in the material accounts may be found to be due to waste which otherwise might be unchecked.

I have heard it argued that the profit and loss on individual orders is of no importance, provided there is a satisfactory credit balance at the end of the year. This might be tenable where the output of the factory consists of one type and size of apparatus, but where there is a diversity of product the cost analysis may show that while the overall margin is satisfactory, one product is being quoted at too high a price and another at too low a price, and that an increased turnover might be realised with a corrected price. I might also add that it is possible on a large order which might extend over one or more years to obtain a check price after a small proportion of the order has been executed. It might then be found that unless some change is made in the methods of manufacture, a loss would be certainly realised at the end of the order. An analysis would then be made item by item, and steps could be taken to bring the manufacturing cost in line with the estimate and so avoid a loss on the complete order.

I might mention that while we use Hollerith cards which have been specially prepared for our product, we do not use these in

conjunction with either Hollerith sorting or adding machines. While these would be justified for a large plant, with a small plant such as ours, the cost of these machines is not justified, and hand sorting and adding on comptometers is adopted. Under our system we can obtain a cost within twenty-four hours of the completion of an order, and only seven days is required to prove whether a loss or profit has been sustained on establishment charges for the past month. The cost of costing per productive hour under normal conditions is .3d.

Having given a brief outline of the works departments and their responsibilities, we will now proceed to examine their relationship in more detail, and see if we can follow their activities and inter-dependence more closely.

Before dealing with the purely manufacturing side I think it would be advisable to note briefly the procedure leading up to the placing of the actual drawings and specifications in the shops. The order having been received from the commercial department, usually refers to the quotation which has been made sometime previously, either to customer's specification or to a tender which had been prepared by the project department.

For railway work, the motors may form part of a very large railway electrification running into hundreds of thousands of pounds, and the design of the motor must be carried out in conjunction with the design of the control auxiliaries and of the mechanical parts of the locomotive or motor-coach. In the case of tramway motors, however, usually a standard type of motor will be called for, with or without modifications; usually with.

If the order is for a completely new design of motor, every endeavour is made to manufacture and test a sample machine or pair of machines before proceeding with bulk manufacture. If it is realised that of one design over 2,000 motors have been built each costing about £500, the importance of manufacture and testing a sample before proceeding with the bulk will be appreciated. The question, however, is often decided by the delivery date, and in a number of cases time does not permit of the sample being made, in which case every possible care must be taken with the design and wherever possible component parts are built up well in advance of the job. For instance, a dummy wooden core may be made in which to try the armature coils, and a wooden model may be made of the motor and tested either on an actual truck or on a dummy truck.

In laying out the design it is necessary, of course, for the designer to have due regard to the machine tools at his disposal and to confine his material as far as possible to standards. Standards may be divided into two categories, standards of material such as copper sizes,

bolts, screws, etc., and departmental standards such as bearing housings, axle caps and other components of motors already manufactured.

Where actual components cannot be used, an attempt is made to adhere to main dimensions in order to minimise the cost of new tool development. For example, perhaps on a railway motor, it is not possible to use existing bearing housings owing to change in type of bearing or size of shaft, but as the tools for a bearing housing cost in the neighbourhood of £30 the spigot diameter, number and size of bolt holes and all other leading dimensions are adhered to, so that the only development incurred will be the cost of the pattern. On the standard sheet indication is made not only of the standard sizes, but also of those sizes which are carried in stock, as this gives the necessary information where questions of quick delivery are important.

Orders.

When an order is received in the works from the commercial department a copy is sent to each section of the organisation which may be concerned in the manufacture of a motor or component. Additional copies are made and sent to every manufacturing department in the works which may be concerned in any way with the work. The procedure which will be followed will depend upon the question as to whether the apparatus is standard for which drawings and specifications and all information are already in existence, or if it is of new design and for which new specifications will have to be made. If, for instance, the order is for a standard tramway motor, similar to many which have been made previously, the engineering department will give instructions to the drawing office to issue manufacturing information to the process and rate department, which department is responsible for making out and issuing the specifications to the stores and to the manufacturing departments through the production department. The drawing office will also issue a drawing list of all drawings concerned, together with material list which will be used by the process department in making out the specifications.

As the drawings become available to the shops, the superintendent goes through each drawing with the process engineer, and the jig and tool engineer to decide on the methods, processes, operations and sequence, type of machine tool to be used, and whether special tools, jigs, or gauges should be made. In making these decisions the quantity to be produced plays the most important part. The amount of money to be spent on special equipment depends almost entirely on the question of quantity to be made. This is influenced also by the decision as to whether the new type of apparatus is one which is likely to become standard or whether it is unlikely that

it will be used on any other railways. The engineering department, who are closely in touch with the traction project department, advise on such matters. The foremen of the various departments are consulted with regard to any special process.

After all such matters have been finally settled the process department and the jig and tool department take over their drawings and get to work. The jig and tool engineer proceeds to make out a list of tool and jigs and gauges which will be available for each component; in doing this he makes full use of any standard tools which may be available, and calls for these by their tool number on his lists. These lists are made on standard printed forms drawn up specially for this purpose, and a full list, one sheet for each component, is made up into folders, and a complete set sent out to the process and rate department, production department, tool stores, and drawing office. Copies are sent to each foreman for those components which concern his department.

The process and rate department then make out the necessary job tickets in line with the job tickets used on previous orders, except modified according to the quantities.

It is my intention to follow quite carefully the procedure, particularly with regard to production, and I propose to do this in dealing with the more complicated case of a motor which is of a completely new design, which I shall now proceed to do. As soon as all the requirements have been agreed as between the motor engineering department, the railway project department and the consulting engineer or the railway company as the case may be, and the engineering calculations have been made, the drawing office receive from the engineering department the information which will enable them to proceed with the drawings.

This information consists of such data as diameter and length of armature, dimensions of commutator, number of conductors with section of copper and number of commutator segments, number of turns and section of copper for the field and interpoles, magnetic section of yoke, gauge of track with clearances, and all other particulars which may limit the internal and external dimensions of the motor. I might mention here the fact that the engineering department and the drawing office are located in the same room, and are therefore able to make and keep continuous contact.

The drawing office proceed with the layouts making first a preliminary general drawing to give limiting dimensions for the components, and afterwards detailing components in a certain definite order determined by the question of delivery of the component concerned. For instance, as the yoke is not only a complicated drawing but entails the making of a very complicated pattern before the casting can be obtained, this is the first part to have the drawing office attention. Malleable iron castings are also amongst the first

to be detailed. Finally, such drawings as cable connections, covers, etc., are left until the last, and in fact in some cases it may easily happen that the complete drawings are not actually issued until the motor is partially completed. This is particularly the case where a sample motor is being built ahead of the bulk.

During the progress of the design collaboration takes place on the drawing board between the draughtsman and the pattern makers in the case of cast components, and with the works superintendent and/or the tool draughtsman, and the chief rate fixer. Such collaboration is considered to be of great value in obtaining the most economical design. The first drawing to be issued is the drawing list giving a list of drawings which may be expected. This is essential so that the process and rate department may check off the drawings as they appear, and may know when they have received the full complement.

Each drawing includes its own list of materials per unit, which simplifies the work of the specification department. The drawing also refers where necessary to the purchasing specification controlling the material to be used and insulation specifications to control the methods of insulating the various electrical parts. In cases where the design is so radical as to require new insulation specification, these would be prepared in advance by the engineering department and issued to the shops under a general insulation specification number, that is, without reference to any particular job, and would therefore become a standard for future use.

The drawing list is issued in advance to production department to enable them to see that drawings are available in time to meet the delivery dates. As the drawings are complete three copies are sent out to the works through the process and rate department. These are despatched as follows: One is retained for file in the process and rate department, one sent to the inspection department, and one is sent to the tool stores in the shops. A record card is kept in the process and rate department of all drawings received by them, and the signature of the department to whom the drawings are issued is kept on the record card. The drawing office also keep a record of all drawings issued to the process and rate department. If drawings are revised and new copies issued old drawings are withdrawn by the process and rate department and the new one issued in its place. This is also recorded on drawing card record in the drawing office and the process and rate department. As a delivery date will have been fixed either on receipt of order or during the tender stage, the production department will already have added the order concerned to its master programme of works output.

From the drawing list, the production department will prepare a chart showing the dates on which drawings, patterns, castings,

forgings, and other materials, also jigs, tools, gauges, will have to be available to meet the programme of deliveries. They will keep in touch with the various departments and record progress made on progress chart. A chart record is kept for each order of a certain value, and a common one for small orders. A standard form is used and provides for recording receipts of materials and progress of work in shops.

These tool lists are numbered and folders are indexed and the tool numbers are in due course added to the drawing of the component. (For manufacture of standard products the practice is to put list of tools, jig, and gauges on component drawing. For new work this is not practicable, as it involves too many drawings being revised and issued.) As the tool lists are completed the drawings of jigs, etc., are put in hand, and subsequently issued to the tool room for manufacture. Orders are made out on special forms for the purpose and copies sent to all departments concerned, including the cost department.

Each jig, tool, or gauge is given a tool number, and this is quoted on the order to the department, and the cost of manufacture is obtained by the number being quoted on all job tickets. All material requisitions also refer to this number. With a view of keeping down the cost of tools, all drawings are first processed by the department, and a process sheet is issued to the tool department along with the order for the tool. Simultaneously with the preparation of the tool drawings, the process and rate department process the component parts, and all other operations connected with assembly. In the same department material lists and works specification sheets are being made up from the drawings. Special forms are used for this purpose.

Process sheets are drawn up showing the operations to be performed on each component in their correct sequence. They also give the group of machines to be used for each operation, the type or class of labour to be used, the piece work price and time allowed for each operation, the factory expense rate for each machine or for hand labour as the case may be, and the total factory cost including award (cost of living bonus).

The process engineer will call for all operations to be carried out on the best machine available for the purpose, and will assume all conditions to be favourable to good production. (Difficulties may arise which make this impossible, and these will be dealt with later.) Material specification sheets are sent in draft form to the production department to be checked and for information to be added concerning the disposition and supplies of material. Also sheets calling for material which is usually stocked are sent to the stores concerned which fill in the material origin column a statement

as to whether and how much of such material is at the present time in stock.

Ledger card records are kept in the stores, one for each item or class of material, and these show the maximum and minimum amount of quantity of material of that kind which is to be kept in stock. This quantity may be varied from time to time according to instructions from the production department depending upon the volume and type of apparatus on order. All orders for materials to replenish stocks are entered on this ledger card and receipts and issues posted up in columns provided, so as to show what quantity is available or on order at any particular time.

As the specification sheets are dealt with, the quantity allotted to each order is entered on the card and if the quantity is such as to reduce the quantity left below the ordering level, the specification will be marked " ordered for stock " and a requisition for further supplies will be sent to the production department. The sheets are returned by the stores with the stock material filled in, and are scrutinised by the production department who mark which items are to be purchased, and which items are to be made in the shops, and in which department. These draft sheets, now carrying full information regarding the origin of all material are returned to the process department and copies are sent to those departments concerned in receiving material or providing material as " feeder " departments. The sheets are duplicated and in their final form contain all manufacturing information required, such as order number, customer, quantity, drawing numbers, purchasing specification numbers, manufacturing specifications, material quantities, class of material, process sheet number, for all items to be made in the works. Item numbers are also unitised to facilitate costing, and sheets quote the unit number.

The preparatory work in connection with an order is meanwhile proceeding in the process department, which department will in the meantime have processed the drawings and fixed times and prices for all the various operations. Incidentally every job is processed throughout before manufacture commences. The process sheet and the copy of the specification sheet will now be posted to another section of the process department, who make out the job tickets and this section will proceed to duplicate the process sheets, making copies for all departments concerned, including the cost department and wages department.

Job tickets will be made out for each operation and material cards for all stock items. The job tickets are made to cover the quantities upon which the price is based, the quantity on order, time taken to produce, and programme of delivery. In general we endeavour to fix the quantities so that the operator can complete

one job ticket in a week and so obtain regular piece-work earnings payment.

Complete specification sheets and job tickets are sent to the production department for distribution and checking. Material cards are sent to the stores, and the purchasing agent will place orders for material not stocked, and send the production department a copy of such orders. These are recorded and filed under a system which calls for automatic urging when the items are becoming due for delivery. The production department having already fixed the delivery date and added the order to the master programme, sends a monthly report to each department advising the foreman what the weekly production must be.

As the production department is responsible for the output and for the getting in of material from outside, the job tickets which have been previously made out by the process and rate department are filed and issued by the production department as the material is available, and in time to allow the delivery dates to be met.

When difficulties arise due to the non-delivery of materials to the specified dates, re-adjustments have to be made in the production programme, necessitating the bringing forward of work not due for delivery in order to keep the workpeople and machine tools employed. The superintendent decides what work shall go forward out of programme. To check the load on any particular department or group of machines, or section, man hour charts are made up by the production department, and posted in the superintendent's office. These show if any particular section, or group of machines are overloaded or underloaded.

It must be realised that the conditions envisaged by the process department may not in practice be met, owing to certain unforeseen circumstances. For instance the operation may have to be carried out on a different machine owing to a particular machine tool being out of commission or employed on other work, or possibly excess material on castings or forgings has to be machined off, or hard material may be encountered or possibly a higher class of labour may have to be employed or defect in material may necessitate the work being set up more than once. In such a case the rate fixer will give a revised price for the operation, and an addition is made. Such revisions must be approved by the process and rate office. Each week the cost office issue to the superintendent a statement of the extras paid. The man hour charts and the cost returns enable the superintendent to judge the efficiency of processing and also the efficiency of the plant and equipment, and in addition give him all the information upon which to base his recommendations for new equipments.

The foremen's clerks keep all shop records, which include specification sheets before the job tickets and proceed to make out the

job tags from the information supplied on the specification sheets. These tags are specially printed for the purpose and provide for the entering of the order number, pattern number, drawing number, and number of pieces. These are filed according to section and to date the work is required.

When the job tickets are received, which, incidentally, is a notification that material is available, the work tags are issued to the charge hands of the various sections, who arrange with the stores concerned to deliver material for his section, and who will then put the work in hand in his section under his foreman's instructions.

To obtain the material, specification sheets have to be presented at the stores as an authority and the stores clerk will mark off, in the column provided on these sheets, the amount of material issued and the date of issue. As the material is issued the stores clerk will pass material cards, previously issued to them by the process and rate department, for the amount of material issued, to the cost department to enable them to keep account of material used against the wages paid and the finished product. When a man is given a job, he takes the work tag to the foreman's clerk as an authority for a job ticket. He then takes his job ticket to the tool stores and applies for the drawing shown thereon and for the tools, jigs and gauges required which are also shewn on the job ticket. The foreman will arrange for as much of this to be done in advance as possible through the shop labourers and other assistants so that a man may change from one job to another with the minimum of delay. The work tag is attached to the job and follows it through all the operations so that each operator in turn may use it for his authority for his job ticket.

Inspection of Material

Samples of all materials are tested, some being tested in our own works and some at the supplier's works before despatch. Samples are taken from each consignment of insulating materials when they arrive in the works. These are tested for breakdown voltage and in some cases mechanical strength. Malleable iron and steel castings are tested by cutting up a certain proportion and testing for physical properties. Steel forgings are usually tested at the suppliers' works before despatch.

Inspection of Apparatus.

For a product, such as the one under consideration, inspection and intermediate testing plays an important part in the manufacture. Under the chief inspector are one or more inspectors for each department, who check important dimensions of machine parts, and in addition review the workmanship in general. Testing of component parts is a very important matter not only to ensure

that the quality of the product is uniform both for the parts which are seen and those which are unseen, but it is found to be an economy as it avoids the expense of stripping a machine after the final test due to the failure of some component which is difficult of access.

As an illustration of our procedure in this respect, armature coils for a 600 volt tramway motor are tested at 4,500 volts to earth before they are placed in the slots by placing the slot portion in a metal grip. After the coils are inserted in the slots, but before they are connected up, a test is applied at 4,000 volts to earth ; after the leads are connected up but before they are soldered the coil is again tested for 3,000 volts ; after soldering, but before banding at 3,500 volts, and finally tested at 3,000 volts.

It will therefore be seen that the armature is subjected to high pressure test five times during the course of its manufacture at descending values. Barring accidents therefore during the manufacture, it is fairly safe to assume that a coil which will stand up to the initial test of 4,500 volts will be perfectly safe at the final test of 2,500 hot. A table of test voltages is issued to the shops similar to that described for the coils giving different values for commutator, brush gear, and field coils. By followng out this procedure it will be readily understood that it is rarely that breakdown occurs on our test bed.

Mechanical tests on components are carried out as far as possible in a similar way. For example, a completed armature is run at speeds greatly in excess of anything likely to occur in service at least three times during manufacture (for commutator seasoning, balancing, and final overspeed test). Also with brush holders in which the steel pin is pressed into the insulated yoke, pressure is applied to pull out the pin. For mechanical inspections all easily transportable components are taken to definite inspection stations between operations on different machines, and all heavy pieces are inspected before being removed from machine on which the operation has been done. If any component of a batch inspected is rejected due to poor workmanship, the workman concerned will have to produce another piece at his own expense as regards time, or the inspector will reduce the number on piece work ticket and tag.

Armatures and other assemblies have special inspection tags attached at commencement of operations and these call for definite stages of inspection and tags have to be signed by inspector at each stage before passing to next stage. Machines arrive at test department with these tags attached and after testing and final inspection these are removed and finished machine inspection tag substituted to authorise shipment to warehouse. These tags are collected and filed in chief inspector's office. Inter-departmental transport is covered by issue of factory receipts between foremen's offices and to enable production department to keep record charts

up to date, copies of all receipts are sent to production department office.

General.

To try to describe a rather elaborate organisation in the course of about one hour is difficult except in outline, but even an outline would be inadequate unless I referred to a number of important parts of our organisation which have considerable effect upon economical production. It is necessary to enlist and maintain the interest and co-operation not only of the staff but also of our workpeople, and I will proceed to describe as briefly as possible certain measures taken with this in view.

Engineering Society.—We have an engineering society at the meetings of which we encourage the attendance of the foremen and workpeople. At these meetings, which are held in the evening, some member of our organisation, or in some cases an engineer representing some allied interest gives a paper dealing with some phase of engineering or manufacturing and at such papers we encourage and obtain very good discussions.

Foremen.—There is a foremen's committee which meets the manager each month to discuss all matters affecting efficiency. Recently we have established a bonus scheme based on the relation of factory expense to productive labour. This was established in the first place by calculating year by year over five previous years the total expenses of a number of items over which the foremen can exercise some control; such items are miscellaneous labour, miscellaneous material, machine tool maintenance, small tools, power, water, gas, heating, etc. Over the same years the total hours of productive labour were calculated and the factory expense expressed as a percentage. If any reduction is made over this percentage the foremen take a share in the saving.

Works Committee.—There is also a works committee which meets the management once per month. This gives an opportunity for the workpeople to bring up any matters which may affect their welfare, and which may embody some seed of discord. At the same time it gives the management an opportunity to give to the workpeople any information regarding the state of business and the possibility of future orders.

Safety-First Committee.—Each Saturday morning a member of the senior staff makes an inspection of all machine tools, chain slings, etc., with respect to efficient protection, and all other points which affect the safety of the workpeople. A report is issued, copies of which are sent to the works superintendent and the manager. On subsequent inspections the previous report is taken round with a view to checking off and seeing if all the necessary modifications have been made. An electrical inspection is made

once per month by the chief inspector and the report circulated in the same way. Each month a safety-first committee, to which representatives are appointed from each department in the works, meets and consideration is given to the reports and to other matters which might be raised by any other member of the Committee.

Sports Association.—We have a very active sports association with our own ground and sections of nearly every kind of sport. A contribution of 2d. per week is asked from each employee, and, although the payment is quite voluntary, 99 per cent. of the employees are members of this association.

Conclusions.—In conclusion, I would say that while our function is primarily to manufacture a reputable product and to provide a profit for our shareholders, we try to keep in view the fact that we are a small part of the economic system and that those employed in our factory must perforce spend a large proportion of their waking time in the surroundings provided for them in the factory. We therefore make it our duty to make these conditions as congenial as possible, by providing a clean and tidy factory, by giving what attention we can to the material requirements of our employees, and by stimulating an interest in their work.

We try to make each member feel that he is in his own sphere responsible for the reputation of our name, and, for instance, as visitors who come to our works often pay some compliment regarding the cleanliness of the machine tools or the tidy aspect of the factory or the apparent interest of the workpeople, and we take care that these compliments are passed on to the workpeople concerned.

In conclusion I would like to acknowledge the assistance I have received from members of my works staff in the preparation of this paper, particularly Mr. A. Hodson, who has given considerable assistance in the description of the works' routine.

Discussion

MR. SCHROEDER: I feel rather bewildered in starting this discussion because the subject with which the lecturer deals has been treated in such an elaborate manner that I have scarcely recovered sufficiently to find any holes into which my little pin could be stuck. However, at the outset one of the lecturer's remarks rather puzzled me. It was to the effect that the reliability required from his product was so great that a good deal of time and energy had to be spent in obtaining tests during the period of manufacture. I cannot help thinking of the people who have to manufacture at competitive prices, vacuum cleaners and other domestic machines which no doubt most of us possess, and perhaps have occasionally had to attend to. That brings me rather to the point which is more serious: that is, in many cases, the products which we have to manufacture

are of a far different nature, and I feel that the elaborate and comprehensive survey Mr. Fletcher has given us can scarcely apply to the majority of industrial manufactures. At the same time, I do think that we can obtain a great deal of benefit from the details which Mr. Fletcher has given us of the various ways of checking up the requirements of each individual component, the arrangements adopted to obtain flow production, and prevention of delay at the final assembly stage.

One point in particular, in which perhaps some production engineers are not interested, is the time taken over the various tests and the number of high voltage tests which were made on the armature before its final destination in the despatch department. In the manufacture of normal industrial motors of all types such an amount of testing on the armature cannot possibly be given to standard machines. My experience is that a large number of high voltage tests tends to destroy insulating properties, and I feel that it is better not to risk breaking down the insulation, particularly when motors are used on low voltage normal power supplies, merely for the sake of recording tests.

There is another point on which I should like to have information and that is what would be the time taken from the day an order is received to the first real commencement of work in the shops? To my mind according to the system described, one should really require to carry out elaborate and detailed process analyses, and for those of us who have to manufacture to the requirements of the average buyer to-day, six weeks is quite a long time, and I should like to get some idea of the time taken between the receipt of an order and the final tests. Again how is it possible to make a budget when conditions, particularly in regard to railway work, have changed so rapidly during the last five years or so?

From the vast amount of detail work in records, it seems to me that of the total works cost, the purely clerical side is going to represent a very heavy percentage, and I can quite understand that this will depend on the number of machines to a given order. It seems that sometimes there must be a relation, but on the average any figure taken must be very unreliable and therefore greatly reduces the value of the elaborate and detailed card system.

A further point is what happens to this colossal arrangement of schedules, charts, and cards when one of the main suppliers has an accident and raw material which requires weeks to produce, urgently wanted by Mr. Fletcher, is, for example, sent to a wrong address or lost in transit. What happens to the elaborate scheme in such a case? It is always easy to criticise a scheme on paper, but I have no doubt that the system described would be satisfactory in practice, particularly bearing in mind the expensive type of apparatus being produced and the usually large value of each

individual order. In conclusion I feel that we are much indebted to Mr Fletcher for the interesting way in which he has presented a difficult subject and I shall be interested to receive his replies to the few points I have raised.

MR. L. BARKER: I believe I am right in saying that it was mentioned in the lecture that apprentices were taken on with a view to the skilled labour that might be required for quite a long period ahead. That, to my mind, seems rather difficult. The other point was the tools list, which did not indicate the operations for which the tools were required. Then an operation sheet was shown which came from the process department. It seems that if these two could be combined then the tools and gauges could be shown alongside the operation it would be an advantage. In any case if tools are listed on drawings it seems a definite advantage to mention the operation for which they are required.

MR. PUCKEY: I have been very interested in Mr. Fletcher's remarks this evening, although I was rather disappointed to find that the paper did not deal specifically with the production of electric motors but was rather one on the organisation of the factory. Mr. Fletcher does not state to whom the chief inspector is responsible. Perhaps he would enlighten me on this point. He also mentions at various intervals the shop clerks who are in each department and I shall be glad to know whether these shop clerks are responsible to the foreman of their particular section, or whether they are responsible to the production control department. Again, the question of lifting and shifting material is discussed but no reference is made to the person or persons responsible for this work. I assume this comes directly under the control of the progress section of production control department. It was mentioned that the operation layout which gives a list of all tools required for the production of the part concerned, is sent to the drawing office. I cannot quite understand why this should be so because it appears to me that the drawing office is not in general interested in the tool numbers used in the production of a part.

I was rather surprised to hear that when a new contract is received it is necessary to send to the stores asking the latter to get out a list of the actual material they have in stock suitable for the various components comprising the contract. This is certainly not in accordance with standard practice where a stock records control section is provided, usually in the progress section of the factory, and all information concerning stocks of material is taken direct by the progress clerks from the stock records instead of relying on the storekeepers sending up the necessary information. It appears far more necessary to control stocks of material from the office end than from the stores end, and is certainly in my experience a very definite check on stores usage. It also, of course, has the

outstanding convenience that it is possible to foresee shortages at a much earlier date than would be possible through having to refer such queries to the stores.

I was very interested indeed to hear Mr. Fletcher's remarks on the question of staff bonus. This problem has been rather a sore one with members of the staff for over a period of many years and it is interesting to hear of at least one firm that has definitely put such a scheme into practice. There is one point, however, that I should like to dwell upon in commenting on staff bonus, and that is what I might call the "terms of reference of such bonus in its relation to any particular staff member." My own experience has been that it is advisable to limit the possibilities of earning bonus by any member of the staff to the actual work for which he is responsible and not to give a general bonus to all staff members embracing the running of the factory as a whole, irrespective of whether one member has more responsibility than another. Taking an actual case, I have found that the more unskilled and inexperienced an operator is, the narrower should be the confines of his bonus-earning capabilities, that is, he will not interest himself in a bonus scheme where he cannot be responsible for the conditions earning such bonus. Going to the other end of the scale, the manager who obviously controls all departments should have his bonus based on the results obtained from the savings in all departments.

MR. ACLAND: There should not have been any misunderstanding as to the subject of the lecture, as a very excellent synopsis was circulated with the tickets for this meeting. The system that Mr. Fletcher sets out sounds more elaborate to describe than to use. I think we ought to try and find some way of giving a bonus to the foreman, tool setter, and staff. The suggestion was made that if you make it general it entirely defeats its object. The foreman, however, gets his bonus because somebody else does the work.

MR. FLETCHER: In reply to Mr. Schroeder I must agree that the manufacture of traction motors presents aspects which are less pronounced in the manufacture of industrial machines, and it is essential to take precautions both with regard to inspection and intermediate testing which could not perhaps be justified in the case of industrial machines which are not subject to so arduous conditions of service.

Nevertheless, even from the point of view of manufacturing costs, many of the precautions taken can be justified on the grounds of economy. For instance, if a component has to be scrapped due to some defect, it is more economical to test it, and scrap it as a component rather than build it up into a more complete part and have a failure on final test resulting in dismantling of a considerable amount of work.

With regard to the testing of armature windings, this method is not confined to traction material, but is also used in the manufacture of industrial machines at our other factories, generally upon grounds of economy.

With regard to the danger which Mr. Schroeder suggests of straining insulation during a large number of tests, this may apply to extra high voltage machines where the thickness of insulation is decided by the voltage required, and where a test of three or four times the working voltage may cause excessive stress. On relatively low voltage machines, however, mechanical considerations play a part in deciding the thickness of the insulating wall; in other words, in the slot portion of the coil the thickness of insulation is usually more than is required to withstand the voltage only. Consideration, however, must be given to the fact that the coil has to be handled in winding into the machine, and with the thickness of wall usually adopted for mechanical reasons, there is usually no difficulty whatsoever in obtaining a value of insulation which can withstand high voltages, without any risk of incipient failure. In fact, a breakdown in a coil nearly always results from some mechanical defect in the insulating wall, and it is imperative, particularly on a traction motor which is subject to vibration, that such mechanical defects should be found and eliminated.

The results obtained fully justify the procedure described, as on traction work a failure to earth is almost unheard of.

Mr. Schroeder also raised the question of the time factor in view of the procedure adopted, and asks what time is taken from the day the order is received to the first real commencement of the work in the shops. In the case of a standard design which requires no engineering development, a copy of the order is received by the production department the same day as it is received in the factory, and full manufacturing information will be issued to the shops within two days. In the case of a standard tramway motor, such limiting parts as yokes and other castings may be in stock, in which case work could actually commence within five to six days from receipt of the order.

In cases where the castings are not in stock, the order for the castings would be placed within four days from receipt of the order, provided they are bought to a schedule of material prices, which often obtains.

With regard to the time which elapses between receipt of an order and testing, this would be in the case of a tramway motor for which castings are in stock five to six weeks; in the case of a standard design, but where castings have to be ordered, nine to ten weeks; in the case of an absolutely new design requiring complete set of new drawings and for which patterns have to made, quotations obtained for castings and other material, the time required would

be sixteen to eighteen weeks. The system, however, is quite elastic and on one occasion an entirely new motor was designed and manufactured within six weeks from receipt of order.

With regard to mishaps which may occur during manufacture, and which frequently occur due for instance to defective castings or scrapped work, this is a condition which any system must be prepared to meet and cater for. In giving delivery dates, we always include a contingency to allow for average conditions, so that in cases, where the material defects are small, the delivery date can be anticipated. In cases where the conditions are abnormally bad, the production department is automatically brought into action, and energetic steps are taken to replace the defective material. On the other hand, defective material has to be legislated for, whether a system is elaborate, meagre, or non-existent, and there is no doubt that our system, embodying as it does an inspection of material at the suppliers' works reduces the amount of defective material to a minimum. A further precaution which is taken is to order an excess of requirements in the case of large orders, based on our experience of the components concerned.

In reply to Mr. Barker, I agree that it is extremely difficult to forecast for several years with any degree of accuracy, the requirements of skilled labour. We know from experience over past years what our average annual requirements have been and we take this as a basis.

With regard to tool lists, these are given in operation sequence for each component and are decided upon before the process sheet sequence is made up. By issuing the tool list separate from the process sheet, it is possible for the two departments—process and rate and tool D.O.—to carry on side by side, without waiting for each other, thereby saving time.

It was mentioned in the outline of the system that a decision is made regarding the tooling ; that is, whether full tool equipment or only partial equipment shall be made, before either department commences detailing operations, etc. This decision is made on quantity on order and possible future requirements.

Where motors or other apparatus are definitely standardised, I agree that it is an advantage to have all information on the drawing, and this is eventually added. To adopt this method on new jobs before commencing manufacture would considerably delay the starting date and involve expense in drawing revisions.

With regard to the queries raised by Mr. Puckey, theoretically in my view the chief inspector should report directly to the management, and be independent of the manufacturing section of the organisation, and whether this is strictly adhered to or not depends very largely upon the factory superintendent himself. As it happens, in our own factory the works superintendent regards the quality

of the product as of greater importance then even cost or output, and in such cases it is not so important that this principle be strictly adhered to.

With regard to shop clerks, the system of wages cards is controlled by the accounting department, but with regard to discipline and all other matters they are responsible to their respective foremen.

In a small factory such as ours the transport is not centralised, as could be advantageously done with a larger factory, but material is moved from department to department by labour under the control of the department sending out the material.

With regard to the tool numbers, as I have already stated the tool list is not added to the drawings until the first job for which the drawings are made has been completed.

With regard to stock records, it appears to me that our system obviates duplication of work as compared with what Mr. Puckey calls standard practice. The store keeper has an index of all materials in stock and if a stock records control section were in commission they would presumably obtain their information from the store keeper, to fill in information on the material card. The store keeper actually is in an office adjacent to the production department, and is responsible for keeping up stocks; as he comes directly under the chief production engineer, it appears to me that he functions in exactly the same way as the stock records control section.

I am very interested to hear Mr. Puckey's remarks regarding staff bonuses, and I agree in general that such schemes are liable to raise all kinds of difficulties. Prior to the present bonus scheme we had one in operation which was based on output. An output bonus is very satisfactory where the factory is working up to its maximum output, or where in fact special measures have to be adopted to obtain the output which is required to fulfil orders. Where a factory is working below its maximum output, however. the output depends upon the orders received, and is quite independent of any special endeavours on the part of the staff of the factory.

A bonus based on reductions of factory expenses controlled by the foremen, is of considerable benefit to both factory and foremen themselves, and there is little doubt that in the few years we have been operating this scheme, a very decided interest has been taken in all factory expenses by the foremen, and we are quite satisfied that very considerable reductions in factory expenses have been effected.

I wish to thank Mr. Acland for his remarks with regard to my treatment of the subject. It would have been no more difficult for me to have described actual manufacturing processes than the system underlying the production of a specialised product, but I adopted the present line very largely in view of the title of your Institution. In any case, as Mr. Acland has stated, the synopsis

which I understand was circulated with the tickets, would I think give a clear indication as to the general trend of the paper.

Also I agree that an attempt to describe almost any system gives an idea of complexity. Our system, however, works smoothly, being the result of an evolutionary progress over about fifteen years, taking as a basis a very similar system which had been developed at the parent factory over a period of a further twenty years.

I do not agree with Mr. Acland that in our own system a foreman gets his bonus because someone else does the work. He only gets a bonus if the expenses of his department bear a smaller relation to the productive hours than they did over the period which was selected for setting up the bogie.